Forintek Canada Corp.

April 1989
SP-31
ISSN 0824-2119

# Kiln Operator's Handbook for Western Canada

J.F.G. Mackay
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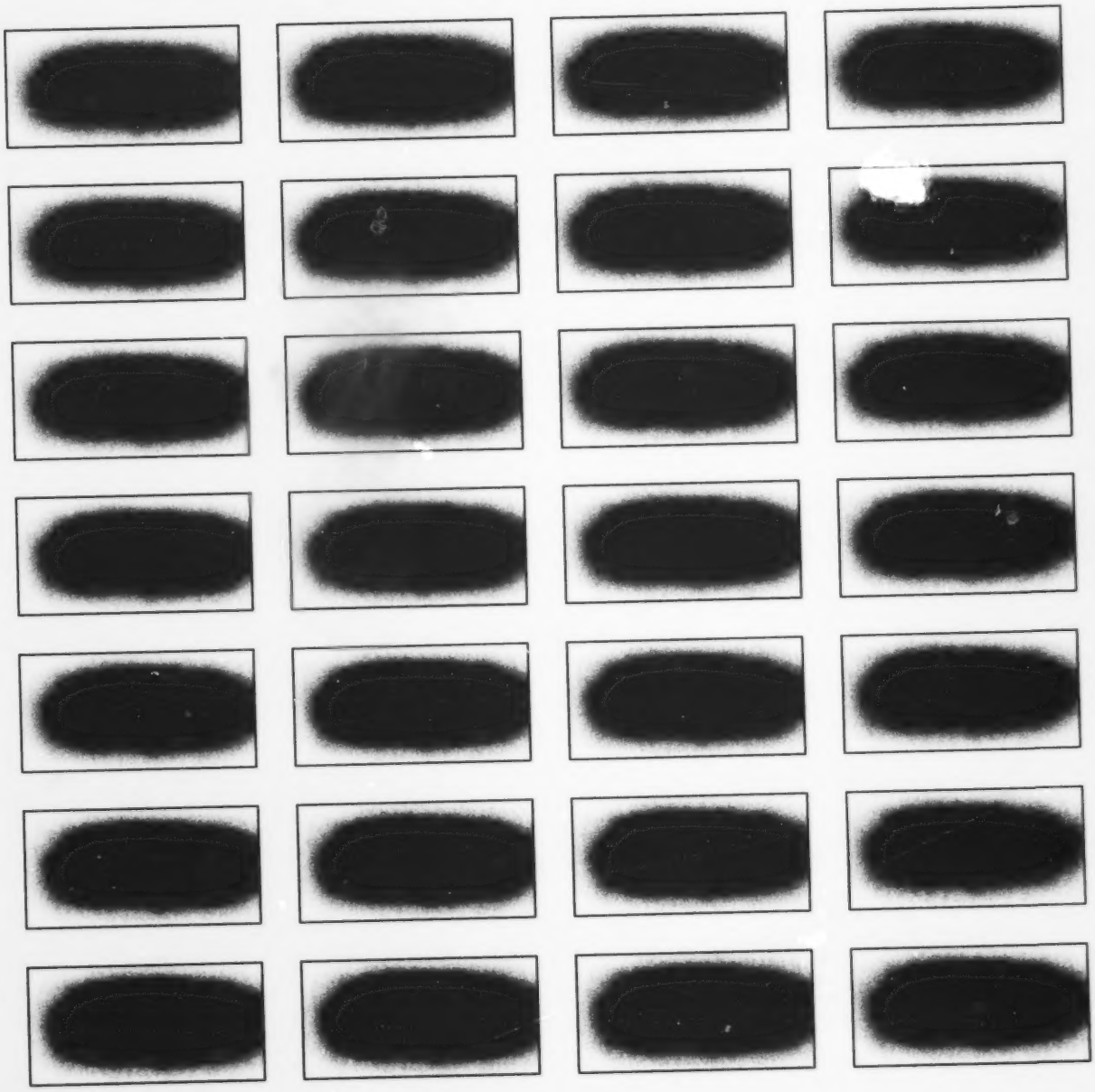

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# KILN OPERATOR'S HANDBOOK FOR WESTERN CANADA

by

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Special Publication No. SP - 31

ISSN # 0824-2119

89-05989/

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# FOREWORD

This handbook replaces "Kiln Drying of Western Canadian Lumber" prepared by G. Bramhall and R.W. Wellwood in 1976. This edition is now out of print, over 3000 copies having been distributed attesting to its popularity. The intent with this replacement is to recognize new technologies and techniques that have developed during the past 12 years and at the same time to delete some topics that are now of lesser interest. Basic principles of course do not change, hence in many areas the present authors have extracted freely much of the material contained in the earlier manual.

It should be recognized that many subjects have been discussed in general terms only and may not therefore answer specific questions operators have with respect to individual kilns and products. Enquiries on individual items can be directed to Forintek Canada Corp. at the address shown or by telephoning (604) 224-3221.

Imperial units of measure that are used by the lumber industry in Western Canada have largely been used in this publication.

The authors wish to acknowledge the assistance of S. McIntyre and D.M. Wright, technologists in the Lumber Manufacturing Group, in the preparation of this handbook.

# INTRODUCTION

The moisture content of a standing tree ranges from about 35 percent in the heartwood of some softwood species to about 200 percent in the sapwood of some species. Removal of moisture from lumber during its manufacture is traditionally called **seasoning** or **drying**. Commercial drying practice infers the maintenance of good quality in lumber and the removal of stresses which develop during some stages of drying. Since wood, on exposure, will ultimately reach a moisture content determined by the temperature and relative humidity of the surrounding air, there are many advantages to drying before placing lumber in service. Some of these are:

1. **To provide dimensionally stable material which can be cut or turned to exact dimensions.** Wood will swell or shrink with changes in its moisture content. If it can be dried to the moisture content it will ultimately attain in use, and is then placed in a reasonably stable environment, further changes in dimensions will be imperceptible. For this reason, manufacturers of furniture and other high-quality products made from wood should be extremely careful about maintaining a proper and stable relative humidity in their plants.

2. **To eliminate warping, splitting and checking of products in use.** When wood dries, the outer surfaces dry first resulting in surface shrinkage and drying stresses. If these stresses exceed the strength of the wood it may check and split. Properly controlled drying eliminates or minimizes these defects and ensures that they will not occur after lumber is placed in service.

3. **To render wood less subject to biological stain, decay or insect attack.** Biological stains and decays are caused by the growth of fungi which use wood or its contents as food. Wood at less than about 22 percent moisture content is immune to fungal attack. Wood which has already been infected with the spores of these organisms is sterilized at temperatures of more than about 150°F (65°C), but can be reinfected if it becomes damp. Wood dried to less than about 10 percent moisture content is not attacked by insects. Drywood termites and certain beetles however, will attack at lower moisture contents.

4. **To prepare for further treatment.** Wood must be dried to suitable moisture contents for gluing and for impregnation treatments. For glued-laminated timbers the moisture content should be about 11 percent and for the gluing of softwood plywood, 3 to 4 percent.

   Wood intended for preservative or fire-retardant treatment should be dried to the moisture content it will attain in service so that inevitable drying checks can be treated with preservatives. In the case of fire-retardant treatment, drying permits the maximum uptake of fire-retardant solutions.

5. **To reduce the weight of lumber and thereby minimize shipping and handling costs.** Shipping charges for lumber transported by rail or truck are based on shipping weight. There is therefore, a direct economic benefit in shipping dry lumber. Traditionally, this has been the prime reason for drying softwood dimension construction lumber in areas serviced by railways.

All Canadian lumber that is graded according to the rules of the National Lumber Grades Authority (mainly construction grades) may be stamped as "dry" provided that it has been dried to a moisture content not exceeding 19 percent. Other grades such as clears, selects, and all wood that is to be resawn or further manufactured, is generally dried to a level mutually agreed between supplier and purchaser. In this second category moisture contents are usually in the 8 to 12 percent range.

# CHAPTER 1

## Structure of Wood in Relation to Drying

The behavior of wood in relation to changes in moisture content are very much due to the structural features of the wood, the most important of which are described below.

Trees can be divided into two main groups: softwoods with needle or scale-like leaves, and hardwoods with broad leaves. In western Canada typical softwoods are the pines, firs, spruces, hemlocks and cedars; while the very much less abundant, commercially important hardwoods include aspen, alder, birch and broadleaf maple.

A crosscut log of a softwood is shown in Figure 1. From the center outwards are three zones of wood known as the pith, the heartwood, and the sapwood, while outermost is the bark.

Other visible features are annual rings running in concentric circles around the pith and radiating outwards, one ring of wood being formed in each year of growth. Each annual growth ring is composed of springwood and summerwood, also known respectively as earlywood and latewood. Earlywood is formed at the beginning of each growth season and is characterized by being light in color relative to the latewood formed later in the summer. The only other feature which might be visible to the naked eye on the crosscut face of some softwood logs would be narrow strands running in a radial direction, that is in a direction from the outermost wood towards the pith. These are referred to as rays.

Between the bark and outermost sapwood is a very narrow layer of cells called the cambium. These cells divide each growing season to form a new layer of bark to the outside and a new growth ring of wood to the inside of a standing tree. In any cross-section of a log, the oldest wood is nearest the pith and newest or youngest wood is immediately under the bark.

With the help of a magnifying glass or a microscope it is possible to distinguish detail in the wood just described. Looking down on the surface of a crosscut, the wood will resemble a network with openings of various sizes and shapes. The openings are the central cavities of the hollow cells which are formed during the growth of the tree. Figure 2 shows a highly magnified block of softwood and the top surface (A) is the surface just referred to. The sides (B and C) are clearly different. B shows the detail which is found on the edge of a flat-sawn board. Side B is known as the tangential surface because it is cut in a direction which is tangent to the circumference of annual rings. Side C is the radial surface because it is cut along the radius of the log. Note that the rays run in the radial direction.

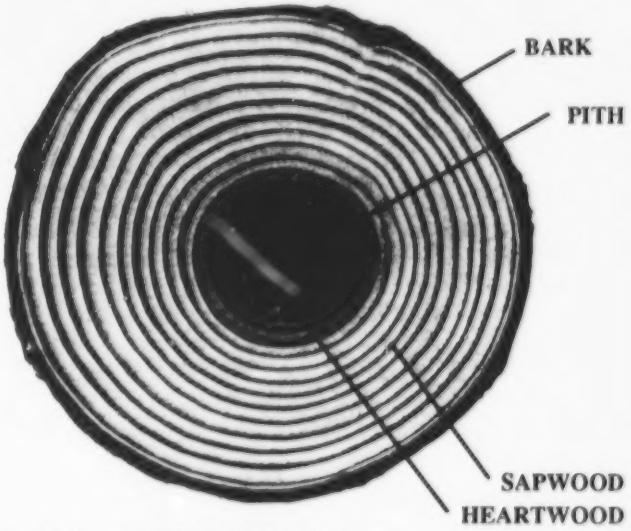


Fig. 1 Cross-section of softwood log

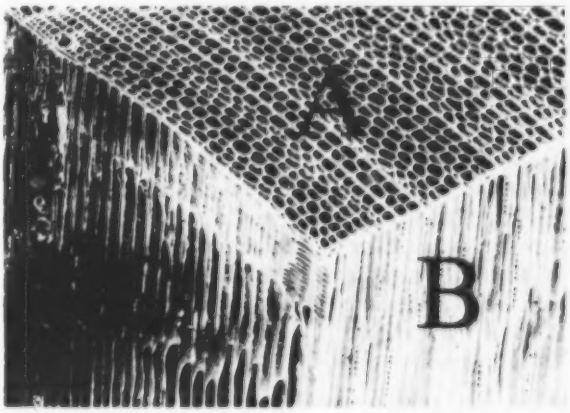


Fig 2 Microscopic detail of a block of softwood

The openings visible on surface A can now be recognized as the cavities of the long cigar-shaped cells totally visible on sides B and C. A cell wall of a particular thickness, depending on the function of that cell, encloses each cavity. The functions of these cells, which run in a direction up and down a standing tree, are mechanical support to maintain the tree in its upright position, and water transport in the direction from roots to leaves. The ray cells, which run at right angles to the length of a trunk, serve to transport materials from the outerwood to the innerwood at any level within a trunk.

All of the wood in a tree does not actively conduct water. In its early years of life, a tree seedling will have only sapwood in its main stem; that is, wood which is functional in conducting water. As a tree ages and new wood is laid down in growth rings around the outside of the trunk immediately under the bark, the older wood towards the center of the trunk undergoes a change both in function and appearance. It ceases to transport water and becomes instead a storage area of material produced, as the living cells in the sapwood age and die. These materials, usually referred to as extractives, are colored and they give this wood a darker color than the younger sapwood. This inner darker wood is called the heartwood.

The older and larger a tree gets, the greater is the proportion of heartwood. This is because the sapwood normally consists of only the last few years of growth. Thus, for example, if it is assumed that only the most recent six years of growth of a tree consist of sapwood, then a 100-year-old tree will contain a greater proportion of heartwood in the cross-section of its butt log than will a 25-year-old tree. The result is that lumber sawn from older, mature trees contain higher proportions of heartwood, while lumber sawn from young trees may contain a high proportion of sapwood.

The difference between heartwood and sapwood is important in lumber drying. Generally the sapwood contains much more moisture than the heartwood, but it is usually more difficult to withdraw moisture from the heartwood because the extractives block up the passages for flow.

In summary, wood is made up of individual cells and the bulk of these are arranged so that their longest dimension runs vertically in a standing tree, or in terms of sawn lumber, lengthwise along a board.

The water that wood contains is present in all of the cells. If we assume a simplified description of a wood cell as a hollow cigar-shaped structure, then the moisture in the wood can be said to be present both in the hollow cavities of the cells and in the cell walls which enclose the cavities. These two locations of the moisture are important in the process of moisture removal.

In the cell cavities is found "free water" and any space in the cavity not filled with this liquid water contains water vapor. In the cell walls is found "bound water". When wood dries, the free water leaves the wood first; that is, the cell cavities empty before the bound water moves from the cell walls. A stage is reached when the cell cavities are empty, but the cell walls are still fully wet or saturated. This stage is called the "fiber saturation point" and it will be discussed in more detail later. The fiber saturation point is important in drying because it is only when moisture begins to move out of the cell walls that some of the important changes in wood properties occur; for example, increase in strength and the onset of shrinkage.

## Specialized Wood Types

### Knots

Knots are normal features of all trees. They represent that portion of tree branches embedded in the stem as a tree increases in diameter. If the branch is live, the knots are **tight** or **intergrown**. If the branch is dead, it does not grow with the growing trunk. As a result, such knots are **loose** or **encased**. Because knot wood has greater density and different grain orientation than normal wood, it has important effects on lumber seasoning. Tight knots tend to remain fixed in sawn boards, although they may check in drying, but encased knots may loosen and fall out.

### Reaction Wood

Reaction wood is a specialized type of wood developed in a tree to support a leaning trunk or a branch. In coniferous trees, it grows on the underside of the leaning part of a tree and is called **compression wood**. In broadleaved trees, it grows on the upper side and is called **tension wood**.

In compression wood, the annual growth rings are usually very wide and appear to have an unduly high percentage of latewood. The usual clear line of demarcation between earlywood and latewood is often lacking in the compression wood of Douglas-fir, for example. Compression wood appears as a half-moon pattern of dark-colored wood on the lower side of the tree or branch. In the green condition, compression wood is distinguishable by its dark reddish color. It is heavy and hard, and when dry has a dull, lifeless appearance which on wetting returns to the dark reddish color of undried wood. Compression wood shrinks longitudinally during drying much more than normal wood and its strength along the grain is much less. As a result, a piece of lumber with compression wood near one face will bow or warp during drying.

Tension wood performs the same function in broadleaved trees as compression wood does in the conifers; i.e., it supports branches and a leaning trunk. Because it is on the upper side and acts in tension, its structural features are quite different from those of compression wood. When cut into lumber, tension wood shrinks abnormally, resulting in warping and splitting of lumber.

### Juvenile Wood

Wood from close to the pith of softwood trees (**juvenile** or **core wood**) tends to have less than average weight. Longitudinal shrinkage is greater than normal; transverse shrinkage is less than normal. Although juvenile wood tends to have the lifeless appearance of compression wood, it lacks its high density and should not be confused with it. It occurs in all trees, but is more prevalent in pines. It is also more prevalent in fast-grown plantation trees than in forest-grown material.

### Wet Wood

Zones of **wet wood** are particularly common in certain species such as hemlock, alpine fir and trembling aspen. There is no precise definition for wet wood. The term is usually applied to pockets of wood having one or more of the following characteristics: high moisture content, presence of bacteria (but not decay-producing fungi), an unpleasant odor, higher pH than adjacent wood, and lower permeability than is normal for the species. The wood has an abnormally high water content with a translucent or water-soaked appearance. This condition develops only in living trees and does not originate through soaking logs or lumber in water.

## Microscopic Features

Wood is composed of cells (thin walls of wood substance surrounding minute cavities) mainly oriented in the vertical plane of a stem. Cell wall substance is heavier than water with specific gravity of about 1.5. The amount of cell wall substance per unit volume determines the specific gravity of wood: those woods with thick cell walls are heavy, while those with thin cell walls are light in weight. Since some air is normally present in the cell cavities, a piece of wood will generally float. However, if most or all cell cavities in the wood are filled with water or the wood is extremely dense, it will be heavier than an equal volume of water and will therefore sink.

### Softwoods

Over 90 percent of the volume of a piece of softwood lumber is composed of longitudinally aligned fiberlike cells, or **tracheids**. These cells are typically 0.10 to 0.25 inch long (2.5 to 6.4 millimeters) with a diameter about one one-hundredth of their length, and with a central cavity or **lumen** occupying about three-quarters of the cell volume. The tracheids, which are arranged in regular radial rows, perform the dual function of conveying water and providing mechanical support for a tree. Free water in cell lumens moves from one tracheid to the next through **bordered pits**.

Also present is a system of horizontally aligned cells or **wood rays**. In living trees these cells carry dissolved food materials radially inward from the living cambium.

Some woods (pines, spruces, larches, Douglas-fir) have both vertical and horizontal systems of enlarged cavities called **resin canals**. Resin (pitch) will often exude from these canals during seasoning and can be detected on end and flat grain as small droplets. In some species resin canals are formed only when a tree is injured during growth. The occurrence of occasional pitchy streaks in western hemlock, which normally has no resin canals, furnishes a familiar example. Pitch may also occur in pockets or openings extending parallel to the annual growth rings.

### Hardwoods

The structure of wood of broadleaved trees (hardwoods) is more complex than that of softwoods because more cell types are present in hardwoods. The most obvious difference is that in wood of broadleaved trees there are large vertical ducts called **vessels**. Vessel elements can be very large in diameter (0.01 inch or 0.25 millimeter). Approximately one-half of a piece of hardwood is composed of **fibers**. Their function in a tree is primarily one of mechanical support. The wood rays in hardwoods are more prominent than those in softwoods and in some are large and readily visible by the naked eye. The diversity in structure of hardwoods results in a much greater variety in seasoning behavior than occurs with softwoods.

## Submicroscopic Features

The cell wall structure of softwood tracheids and hardwood fibers are similar. The cell walls of both are composed of thread-like structures of cellulose called microfibrils. When water is removed from the cell wall the microfibrils draw closer together, causing the cell wall to shrink. This shrinkage results mainly in a reduction in cell diameter which in turn results in a very much greater shrinkage across the grain than along the grain during drying. Only moisture contained within the cell wall structure has an effect on shrinkage, therefore all free water in the cell cavity must be removed before any shrinkage of the cell wall can occur.

# CHAPTER 2

# Wood-Moisture Relations

## Moisture In Wood

Wood in its natural state always contains a substantial amount of water, the amount varying from tree to tree, log to log and board to board. Variations in the amount of water in boards sawn from the same log are due mainly to the position in the log from which the boards were sawn. In many softwood species the sapwood is very much wetter than the heartwood. Therefore, boards of the same size sawn from these two locations will contain different amounts of water and the sapwood boards will weigh more than the heartwood boards.

The moisture in wood occurs in three forms:

1. as **free water** in cell cavities;
2. as **water vapor** in the air in cell cavities not totally filled with free water; and
3. as **bound water** absorbed on the cell wall structure.

The moisture content in a sample of wood is defined as the weight of water in the wood expressed as a percentage of the weight of the oven-dry wood. It can be calculated as the difference between the initial (wet) weight and the oven-dry weight, divided by the oven-dry weight and multiplied by 100 percent.

$$MC = \frac{W_I - W_D}{W_D} \times 100\% = \frac{W_W}{W_D} \times 100\%$$

where $W_I$ = initial weight of wood
$W_D$ = oven-dry weight of wood
$W_W$ = weight of water in wood

For example, the moisture content of a piece of wood which weighs 40 grams green and 30 grams oven-dry is calculated as follows:

$$MC = \frac{40 - 30}{30} \times 100\% = \frac{10}{30} \times 100\% = 33.3\%$$

Average green moisture contents for commercially important Western woods are shown in Table 1.

The **fiber saturation point** ("fsp") is defined as the moisture content at which cell walls are saturated with bound water but no free water exists in cell cavities. This moisture content differs in different woods but is usually between 25 and

Table 1. Average Green Moisture Contents (Oven-Dry Basis)

| Species | Moisture Content (%) | | |
|---|---|---|---|
| | Heartwood | Sapwood | Mixed |
| Cedar, western red | 58 | 249 | 62 |
| Cypress, yellow | 32 | 166 | 52 |
| Douglas-fir, coastal | 39 | 151 | 45 |
| Douglas-fir, interior | 31 | 132 | 43 |
| Fir, alpine | 56 | 153 | 65 |
| Fir, amabilis | 55 | 164 | 69 |
| Hemlock, western | 55 | 143 | 85 |
| Larch, western | 35 | 119 | 49 |
| Pine, lodgepole | 38 | 115 | 50 |
| Pine, western white | 62 | 148 | 75 |
| Pine, ponderosa | 40 | 148 | 76 |
| Spruce, Engelmann | --- | --- | 64 |
| Spruce, Sitka | 41 | 142 | 43 |
| Spruce, white | 51 | 163 | 59 |
| Alder, red | --- | --- | 101 |
| Aspen, trembling | --- | --- | 90 |
| Birch, western white | --- | --- | 72 |
| Cottonwood, black | --- | --- | 175 |
| Maple, broadleaf | --- | --- | 71 |
| Poplar, balsam | --- | --- | 135 |

Table 3. Average Tangential and Radial Shrinkage (% of green dimensions) of Some Western Species When Dried From the Green Condition to Oven-Dry Moisture Content

| Species | Tangential | Radial |
|---|---|---|
| Softwoods | | |
| Western red cedar | 4.5 | 2.1 |
| Yellow cedar | 6.0 | 3.7 |
| Douglas-fir | 7.4 | 4.8 |
| Alpine fir | 7.4 | 2.6 |
| Amabilis fir | 8.9 | 4.2 |
| Western hemlock | 8.5 | 5.4 |
| Western larch | 8.9 | 5.1 |
| Lodgepole pine | 6.8 | 4.7 |
| Western white spruce | 6.8 | 3.7 |
| Sitka spruce | 7.8 | 4.6 |
| Western white spruce | 6.9 | 3.2 |
| Hardwoods | | |
| Red alder | 7.0 | 4.2 |
| White birch | 7.2 | 5.2 |
| Western white birch | 9.3 | 6.8 |
| Broadleaf maple | 7.6 | 4.1 |
| Trembling aspen | 6.6 | 3.6 |
| Balsam poplar | 6.4 | 3.9 |
| Black cottonwood | 8.8 | 3.6 |

**Table 2.** Relative Humidity[1] and Equilibrium Moisture Content[2] Table for Use with Dry Bulb Temperatures and Wet Bulb Depressions (°F)

| Temperature dry bulb (F) | Difference between wet and dry bulb temperatures in degrees Fahrenheit | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 22 | 24 | 26 | 28 | 30 | 34 | 40 | 45 | 50 |
| 30 | 89 | 78 | 67 | 57 | 46 | 36 | 27 | 17 | 6 | | | | | | | | | | | | | | | | | | | | |
| | | *15.9* | *12.9* | *10.8* | *9.0* | *7.4* | *5.7* | *3.9* | *1.6* | | | | | | | | | | | | | | | | | | | | |
| 35 | 90 | 81 | 72 | 63 | 54 | 45 | 37 | 28 | 19 | 11 | 3 | | | | | | | | | | | | | | | | | | |
| | | *16.8* | *13.9* | *11.9* | *10.3* | *8.8* | *7.4* | *6.0* | *4.5* | *2.9* | *0.8* | | | | | | | | | | | | | | | | | | |
| 40 | 92 | 83 | 75 | 68 | 60 | 52 | 45 | 37 | 29 | 22 | 15 | 8 | | | | | | | | | | | | | | | | | |
| | | *17.6* | *14.8* | *12.9* | *11.2* | *9.9* | *8.6* | *7.4* | *6.2* | *5.0* | *3.5* | *1.9* | | | | | | | | | | | | | | | | | |
| 45 | 93 | 85 | 78 | 72 | 64 | 58 | 51 | 44 | 37 | 31 | 25 | 19 | 12 | 6 | | | | | | | | | | | | | | | |
| | | *18.3* | *15.6* | *13.7* | *12.0* | *10.7* | *9.5* | *8.5* | *7.5* | *6.5* | *5.3* | *4.2* | *2.9* | *1.5* | | | | | | | | | | | | | | | |
| 50 | 93 | 86 | 80 | 74 | 68 | 62 | 56 | 50 | 44 | 38 | 32 | 27 | 21 | 16 | 10 | 5 | | | | | | | | | | | | | |
| | | *19.0* | *16.3* | *14.4* | *12.7* | *11.5* | *10.3* | *9.4* | *8.5* | *7.6* | *6.7* | *5.7* | *4.8* | *3.9* | *2.8* | *1.5* | | | | | | | | | | | | | |
| 55 | 94 | 88 | 82 | 76 | 70 | 65 | 60 | 54 | 49 | 44 | 39 | 34 | 28 | 24 | 19 | 14 | 9 | 5 | | | | | | | | | | | |
| | | *19.5* | *16.9* | *15.1* | *13.4* | *12.2* | *11.0* | *10.1* | *9.3* | *8.4* | *7.6* | *6.8* | *6.0* | *5.3* | *4.5* | *3.6* | *2.5* | *1.3* | | | | | | | | | | | |
| 60 | 94 | 89 | 83 | 78 | 73 | 68 | 62 | 58 | 53 | 48 | 43 | 39 | 34 | 30 | 26 | 21 | 17 | 13 | 9 | 5 | | | | | | | | | |
| | | *19.9* | *17.4* | *15.6* | *13.9* | *12.7* | *11.6* | *10.7* | *9.9* | *9.1* | *8.3* | *7.6* | *6.9* | *6.3* | *5.6* | *4.9* | *4.1* | *3.2* | *2.36* | *1.3* | | | | | | | | | |
| 65 | 95 | 90 | 84 | 80 | 75 | 70 | 66 | 61 | 56 | 52 | 48 | 44 | 39 | 36 | 32 | 27 | 24 | 20 | 16 | 13 | 6 | | | | | | | | |
| | | *20.3* | *17.8* | *16.1* | *14.4* | *13.3* | *12.1* | *11.2* | *10.4* | *9.7* | *8.9* | *8.3* | *7.7* | *7.1* | *6.5* | *5.8* | *5.2* | *4.5* | *3.8* | *3.0* | *1.4* | | | | | | | | |
| 70 | 95 | 90 | 86 | 81 | 77 | 72 | 68 | 64 | 59 | 55 | 51 | 48 | 44 | 40 | 36 | 33 | 29 | 25 | 22 | 19 | 12 | 6 | | | | | | | |
| | | *20.6* | *18.2* | *16.5* | *14.9* | *13.7* | *12.5* | *11.6* | *10.9* | *10.1* | *9.4* | *8.8* | *8.3* | *7.7* | *7.2* | *6.6* | *6.0* | *5.5* | *4.9* | *4.3* | *2.9* | *1.5* | | | | | | | |
| 75 | 95 | 91 | 86 | 82 | 78 | 74 | 70 | 66 | 62 | 58 | 54 | 51 | 47 | 44 | 41 | 37 | 34 | 31 | 28 | 24 | 18 | 12 | 6 | | | | | | |
| | | *20.9* | *18.5* | *16.8* | *15.2* | *14.0* | *12.9* | *12.0* | *11.2* | *10.5* | *9.8* | *9.3* | *8.7* | *8.2* | *7.7* | *7.2* | *6.7* | *6.2* | *5.6* | *5.1* | *4.1* | *2.9* | *1.5* | | | | | | |
| 80 | 96 | 91 | 87 | 83 | 79 | 75 | 72 | 68 | 64 | 61 | 57 | 54 | 50 | 47 | 44 | 41 | 37 | 34 | 31 | 28 | 24 | 18 | 12 | 7 | 1 | | | | |
| | | *21.0* | *18.7* | *17.0* | *15.5* | *14.3* | *13.2* | *12.3* | *11.5* | *10.9* | *10.1* | *9.7* | *9.1* | *8.6* | *8.1* | *7.7* | *7.2* | *6.7* | *6.2* | *5.6* | *5.1* | *4.1* | *2.9* | *1.7* | *0.2* | | | | |
| 90 | 96 | 92 | 89 | 85 | 81 | 78 | 74 | 71 | 68 | 65 | 64 | 58 | 55 | 52 | 49 | 47 | 44 | 41 | 38 | 35 | 32 | 29 | 23 | 18 | 12 | 7 | 3 | | |
| | | *21.3* | *18.9* | *17.3* | *15.9* | *14.7* | *13.7* | *12.8* | *12.0* | *11.4* | *10.7* | *10.2* | *9.7* | *9.3* | *8.8* | *8.4* | *8.0* | *7.6* | *7.2* | *6.8* | *6.3* | *5.8* | *5.0* | *4.0* | *3.0* | *1.8* | *0.3* | | |
| 100 | 96 | 93 | 89 | 88 | 83 | 80 | 77 | 73 | 70 | 68 | 65 | 62 | 59 | 56 | 54 | 51 | 49 | 46 | 44 | 41 | 39 | 36 | 31 | 26 | 22 | 17 | 13 | 5 | |
| | | *21.3* | *19.0* | *17.5* | *16.1* | *15.0* | *13.9* | *13.1* | *12.4* | *11.8* | *11.2* | *10.6* | *10.1* | *9.6* | *9.2* | *8.9* | *8.5* | *8.1* | *7.8* | *7.4* | *7.2* | *6.8* | *6.1* | *5.3* | *4.6* | *3.8* | *2.8* | *1.3* | |
| 110 | 97 | 93 | 90 | 87 | 84 | 81 | 78 | 75 | 73 | 70 | 67 | 65 | 62 | 60 | 57 | 55 | 52 | 49 | 46 | 44 | 41 | 37 | 33 | 28 | 24 | 21 | 13 | 4 | |
| | | *21.4* | *19.0* | *17.5* | *16.2* | *15.1* | *14.1* | *13.3* | *12.6* | *12.0* | *11.4* | *10.8* | *10.4* | *9.9* | *9.5* | *9.2* | *8.8* | *8.4* | *8.0* | *7.8* | *7.4* | *6.7* | *6.1* | *5.4* | *4.9* | *4.2* | *3.1* | *0.7* | |
| 120 | 97 | 94 | 91 | 88 | 85 | 82 | 80 | 77 | 74 | 72 | 69 | 67 | 65 | 62 | 60 | 57 | 55 | 52 | 50 | 48 | 46 | 42 | 38 | 34 | 30 | 26 | 20 | 11 | 4 |
| | | *21.3* | *19.0* | *17.4* | *16.2* | *15.1* | *14.1* | *13.4* | *12.7* | *12.1* | *11.5* | *11.0* | *10.5* | *10.0* | *9.7* | *9.4* | *9.0* | *8.7* | *8.3* | *8.1* | *7.7* | *7.2* | *6.6* | *6.0* | *5.4* | *4.8* | *4.0* | *2.5* | *1.1* |
| 130 | 97 | 94 | 91 | 89 | 86 | 83 | 81 | 78 | 76 | 73 | 71 | 69 | 67 | 64 | 62 | 60 | 58 | 55 | 53 | 51 | 49 | 45 | 41 | 38 | 34 | 31 | 25 | 17 | 10 | 5 |
| | | *21.0* | *18.8* | *17.2* | *16.0* | *14.9* | *14.0* | *12.4* | *12.7* | *12.1* | *11.5* | *11.0* | *10.5* | *10.0* | *9.7* | *9.4* | *9.0* | *8.7* | *8.3* | *7.9* | *7.4* | *6.8* | *6.3* | *5.8* | *5.4* | *4.6* | *3.3* | *2.3* | *1.1* |
| 140 | 97 | 95 | 92 | 89 | 87 | 84 | 82 | 79 | 77 | 75 | 73 | 71 | 69 | 67 | 64 | 62 | 60 | 58 | 56 | 54 | 52 | 48 | 45 | 41 | 38 | 35 | 29 | 21 | 15 | 10 |
| | | *20.7* | *18.6* | *16.9* | *15.8* | *14.8* | *13.8* | *13.2* | *12.5* | *11.0* | *11.4* | *10.9* | *10.4* | *10.0* | *9.7* | *9.4* | *9.0* | *8.7* | *8.3* | *8.0* | *7.6* | *7.0* | *6.6* | *6.1* | *5.6* | *4.9* | *3.8* | *3.0* | *2.0* |
| 150 | 98 | 95 | 92 | 90 | 87 | 85 | 82 | 80 | 78 | 76 | 74 | 72 | 70 | 68 | 66 | 64 | 62 | 60 | 58 | 56 | 54 | 51 | 47 | 44 | 41 | 38 | 32 | 25 | 19 | 14 |
| | | *20.2* | *18.4* | *16.6* | *15.4* | *14.5* | *13.7* | *13.0* | *12.4* | *11.8* | *11.2* | *10.8* | *10.3* | *9.9* | *9.6* | *9.4* | *9.0* | *8.7* | *8.4* | *8.0* | *7.6* | *7.1* | *6.6* | *6.2* | *5.8* | *5.1* | *4.1* | *3.4* | *2.6* |
| 160 | 98 | 95 | 92 | 90 | 88 | 86 | 83 | 81 | 79 | 77 | 75 | 73 | 71 | 69 | 66 | 74 | 72 | 60 | 58 | 57 | 53 | 49 | 46 | 43 | 41 | 36 | 28 | 23 | 18 | |
| | | *19.8* | *18.1* | *16.2* | *15.2* | *14.2* | *13.4* | *12.7* | *12.1* | *11.5* | *11.0* | *10.6* | *10.1* | *9.7* | *9.4* | *9.2* | *8.9* | *8.6* | *8.3* | *8.0* | *7.5* | *7.1* | *6.7* | *6.2* | *5.8* | *5.2* | *4.2* | *3.6* | *2.9* | |
| 170 | 98 | 95 | 93 | 91 | 89 | 86 | 84 | 82 | 80 | 78 | 76 | 74 | 72 | 70 | 69 | 67 | 65 | 64 | 62 | 60 | 58 | 55 | 52 | 49 | 46 | 43 | 38 | 31 | 25 | 21 |
| | | *19.4* | *17.7* | *15.8* | *14.8* | *13.9* | *13.2* | *12.4* | *11.8* | *11.3* | *10.8* | *10.4* | *9.9* | *9.6* | *9.2* | *9.0* | *8.6* | *8.4* | *8.2* | *7.9* | *7.4* | *7.0* | *6.7* | *6.2* | *5.8* | *5.2* | *4.3* | *3.7* | *3.2* | |
| 180 | 98 | 96 | 94 | 91 | 89 | 87 | 85 | 83 | 81 | 79 | 77 | 75 | 73 | 72 | 70 | 69 | 67 | 65 | 63 | 62 | 60 | 57 | 53 | 51 | 48 | 45 | 40 | 33 | 28 | 24 |
| | | *18.9* | *17.3* | *15.5* | *14.5* | *13.7* | *12.9* | *12.2* | *11.6* | *11.1* | *10.6* | *10.1* | *9.7* | *9.4* | *9.0* | *8.8* | *8.4* | *8.1* | *7.8* | *7.6* | *7.3* | *6.9* | *6.6* | *6.2* | *5.7* | *5.2* | *4.4* | *3.7* | *3.2* | |
| 190 | 98 | 96 | 94 | 92 | 90 | 88 | 85 | 84 | 82 | 80 | 78 | 76 | 75 | 73 | 71 | 68 | 67 | 65 | 63 | 62 | 60 | 58 | 55 | 52 | 50 | 47 | 42 | 35 | 30 | 26 |
| | | *18.5* | *16.9* | *15.2* | *14.2* | *13.5* | *12.7* | *12.0* | *11.4* | *10.9* | *10.5* | *10.0* | *9.6* | *9.2* | *8.9* | *8.6* | *8.2* | *7.9* | *7.7* | *7.4* | *7.2* | *6.8* | *6.4* | *6.0* | *5.7* | *5.2* | *4.4* | *3.8* | *3.3* | |
| 200 | 98 | 96 | 94 | 92 | 90 | 88 | 86 | 84 | 82 | 80 | 79 | 77 | 75 | 73 | 71 | 69 | 68 | 66 | 65 | 63 | 60 | 57 | 54 | 51 | 49 | 44 | 37 | 32 | 28 | |
| | | *18.1* | *16.4* | *14.9* | *14.0* | *13.2* | *12.4* | *11.8* | *11.2* | *10.8* | *10.3* | *9.8* | *9.4* | *9.1* | *8.8* | *8.4* | *8.1* | *7.7* | *7.4* | *7.1* | *7.0* | *6.6* | *6.2* | *5.9* | *5.5* | *5.0* | *4.4* | *3.9* | *3.3* | |
| 210 | 98 | 96 | 94 | 92 | 90 | 88 | 86 | 85 | 83 | 81 | 79 | 78 | 76 | 75 | 73 | 71 | 70 | 68 | 67 | 65 | 63 | 61 | 58 | 55 | 53 | 51 | 46 | 39 | 34 | 30 |
| | | *17.7* | *16.0* | *14.6* | *13.8* | *13.0* | *12.2* | *11.7* | *11.1* | *10.6* | *10.0* | *9.7* | *9.2* | *9.0* | *8.7* | *8.3* | *8.0* | *7.6* | *7.4* | *7.1* | *6.8* | *6.4* | *6.0* | *5.7* | *5.4* | *4.9* | *4.3* | *3.8* | *3.3* | |
| 220 | 98 | 96 | 94 | 92 | 90 | 88 | 87 | 85 | 83 | 82 | 80 | 78 | 77 | 75 | 74 | 72 | 70 | 69 | 67 | 66 | 64 | 61 | 58 | 56 | 54 | 51 | 47 | 41 | 36 | 32 |
| | | *17.4* | *15.8* | *14.4* | *13.6* | *12.8* | *12.1* | *11.5* | *11.0* | *10.5* | *10.0* | *9.6* | *9.2* | *8.9* | *8.6* | *8.3* | *8.0* | *7.7* | *7.4* | *7.2* | *6.9* | *6.5* | *6.2* | *5.9* | *5.6* | *5.1* | *4.5* | *4.0* | *3.5* | |
| 230 | 98 | 96 | 94 | 92 | 91 | 89 | 87 | 85 | 84 | 82 | 81 | 79 | 78 | 76 | 75 | 73 | 72 | 70 | 69 | 67 | 66 | 63 | 61 | 58 | 56 | 53 | 49 | 43 | 38 | 34 |
| | | *17.2* | *15.7* | *14.3* | *13.5* | *12.7* | *12.0* | *11.4* | *10.9* | *10.4* | *10.0* | *9.6* | *9.2* | *8.9* | *8.6* | *8.3* | *8.0* | *7.7* | *7.5* | *7.2* | *6.9* | *6.5* | *6.2* | *5.9* | *5.6* | *5.1* | *4.5* | *4.0* | *3.5* | |
| 240 | 98 | 96 | 94 | 93 | 91 | 89 | 88 | 86 | 84 | 83 | 81 | 80 | 78 | 77 | 75 | 74 | 72 | 71 | 69 | 68 | 66 | 64 | 61 | 59 | 56 | 54 | 50 | 44 | 39 | 35 |
| | | *17.0* | *15.6* | *14.2* | *13.4* | *12.6* | *12.0* | *11.4* | *10.9* | *10.4* | *9.9* | *9.6* | *9.2* | *8.9* | *8.6* | *8.3* | *8.0* | *7.7* | *7.5* | *7.2* | *6.9* | *6.5* | *6.2* | *5.9* | *5.6* | *5.1* | *4.5* | *4.0* | *3.5* | |

1. Relative humidity values in roman type.

2. Equilibrium moisture content values in italic type.

32 percent. Fiber saturation point is important in drying wood since at and above this level there is practically no change in wood volume with changes in moisture content.

**Equilibrium moisture content** ("emc") is the term used to define the moisture content of wood which has been exposed to the same conditions of temperature and humidity for a sufficiently long period to reach equilibrium. A change in temperature or humidity will result in a corresponding change in the equilibrium moisture content of the wood. Relationships between humidity and temperature of air and equilibrium moisture content of wood have been determined and are shown in Table 2. At the equilibrium moisture content, as much moisture evaporates from the wood as condenses on it, so that the moisture content remains constant.

## Vapor Pressure

An understanding of the term **vapor pressure** is necessary to an understanding of the drying of lumber. It is a governing factor in determining the rate of moisture movement and therefore of wood drying.

If a closed container without air is partly filled with water, the liquid will begin to evaporate and vapor will occupy the space above the liquid. As the space above the liquid becomes more and more concentrated with vapor, some will condense and return to the liquid, reducing the net rate of evaporation. Finally, a condition will be reached when the vapor is condensing at the same rate as the liquid is evaporating. The system is then in equilibrium and the space is saturated with water vapor. The pressure in the container is then the **saturated vapor pressure** of water at the temperature. A decrease in temperature will cause some of the vapor to condense, and a new equilibrium will be established with a lower saturated vapor pressure. Similarly, an increase in temperature will result in further evaporation and a higher vapor pressure.

## Relative Humidity

When air holds less than the maximum possible amount of vapor, it is capable of taking up more until the saturation vapor pressure is reached. The ratio of actual vapor pressure to the saturation vapor pressure at any given temperature, expressed as a percentage, is called the **relative humidity** ("rh").

If wet wood is placed in air that is less than fully saturated; that is, its relative humidity is less than 100 percent, water will evaporate from the surface of the wood. The greater the difference in vapor pressure between the wood surface and the surrounding air, the greater will be the rate of evaporation and the drying of the wood.

In kiln-drying, relative humidity is measured by the use of the wet and dry bulb hygrometer or psychrometer (Figure 3).

This instrument or system consists basically of two similar thermometers or temperature sensors. The measuring bulb of one of these (dry bulb) is exposed in the normal manner and reads the actual air temperature. The bulb of the other (wet bulb) is surrounded by a cotton sleeve or wick which is kept moist with water from a reservoir. When exposed to an air current, evaporation from the wet bulb wick cools the wet bulb thermometer, which as a result measures a lower temperature than the dry bulb thermometer. The drier the air the greater will be the rate of evaporation from the wick and the cooling of the wet bulb sensor. This difference between the two temperatures is known as the **wet bulb depression**, and is related to the relative humidity of the air. Table 2 can therefore be used to determine relative humidity if dry and wet bulb temperatures are known.

## Shrinking and Swelling

Bound water is absorbed on the sides of the cellulose molecules which make up the wood cell wall fibrils. During drying below the fiber saturation point, this water is removed and the cell wall components are drawn closer together, resulting in **shrinkage** of the wood.

When wood is exposed to air at a higher relative humidity than is in equilibrium with it, the fibrils absorb water molecules made available to them and move apart. This is the basis for the **swelling** of wood. The shrinkage ratios of wood are different in the various directions. Also, the shrinkage ratios of knots and abnormal wood are different from those of normal wood. Shrinkage, swelling and these differential dimensional changes are the principal sources of problems in the drying, manufacture and use of lumber.

### Shrinkage Data

Table 3 shows some average shrinkage values for selected, commercially important, Western species. The values were obtained on small samples dried under laboratory conditions. Individual boards may shrink or swell more or less than these averages depending on, for example, density, grain angle and size.

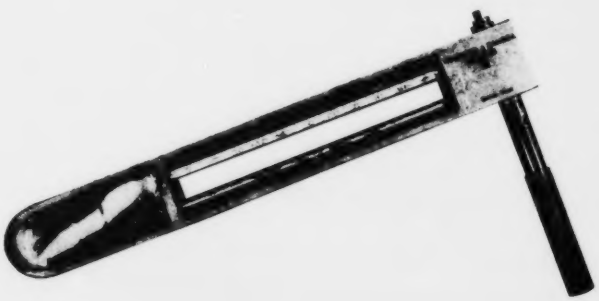

Fig 3 Simple hand-held hygrometer for measuring wet and dry bulb temperatures

## Effect of Moisture Content

The most important factor affecting shrinking or swelling of wood is the change in moisture content below fiber saturation point. Shrinkage is directly proportional to the amount of water removed from the cell walls. It is conveniently expressed as a percentage of the green dimension of a piece, since this dimension is stable at all moisture contents above fiber saturation point. At zero moisture content maximum shrinkage is attained (Table 3). Shrinkage allowances may be approximated using the following equation:

$$S = \frac{30 - M}{30} \times S_{max} = \left(1 - \frac{M}{30}\right) \times S_{max}$$

where $S$ = percentage shrinkage
$M$ = moisture content for which S is to be calculated
$S_{max}$ = maximum shrinkage for the species (e.g. from Table 3)
30 = assumed fiber saturation point.

Examples of the application of this equation are given below.

Example 1:

A wide, flat-grained board of western hemlock is dried from the green condition to 12% MC. What percent shrinkage in width should be expected? Assume fsp is 30%.

Tangential shrinkage of western hemlock (from Table 3) to 0% MC is 8.5%. Therefore the percentage shrinkage to 12% MC is expected to be:

$$\frac{30 - 12}{30} \times 8.5\% = 5.1\%$$

Example 2:

If a normal 6 inch wide, flat grain board of Douglas-fir is dried from the green condition to 15% MC, its width is reduced from 5.82 inches (148 mm) to 5.61 inches (142 mm). The percentage shrinkage can be calculated in the following manner:

$$\frac{5.82 - 5.61}{5.82} \times 100\%$$

$$= \frac{0.21}{5.82} \times 100\%$$

$$= 0.036 \times 100\% = 3.6\%$$

This corresponds closely with the expected tangential shrinkage of a Douglas-fir board dried from the green condition to an MC of 15%.

$$\left(\frac{30 - 15}{30} \times 7.4\% = 3.7\%\right)$$ (Table 3)

Example 3:

Radial (across the face) shrinkage of vertical grain western hemlock is expected to be 4.3% from the green condition to a MC of 6%:

$$\left(\text{i.e., } \frac{30 - 6}{30} \times 5.4\% = 4.3\%\right)$$

The width at 6% MC of a vertical grain board which is 5-3/4 inches (146 mm) wide in the green condition can be calculated as follows:

$$\text{dimensional change} = \frac{5.75 \times 4.3}{100} = 0.25 \text{ inch}$$

$$\text{or} \quad \frac{1.46 \times 4.3}{100} = 6.28 \text{ mm}$$

width at 6% MC = 5.75 - 0.25 = 5.50 inches
or 146 - 6.28 = 139.72 or 140 mm

## Effect of Wood Density

The denser the wood the greater the shrinkage can be expected for a given reduction in moisture content. Thus, hardwoods as a group shrink more than softwoods, and Douglas-fir shrinks more than western red cedar. Where there are variations in density in any species, the lighter pieces shrink less than the heavier ones at the same moisture content.

## Effect of Grain Direction

Wood does not shrink (or swell) equally in all directions. Its structure results in shrinkage behavior which varies between the different structural directions of the wood. As stated earlier the bound water is responsible for shrinking and swelling by leaving or entering the spaces between the fibrils in the cell wall. Since the fibrils are lined up close to parallel to the long axis of the fiber, and the fibers are lined along the grain of the wood, any movement is across the grain of the wood, referred to as transverse shrinkage or swelling, and almost none along its length.

There are two principal transverse directions, namely radial and tangential. The wide surface of a flat-sawn board is sawn in the tangential direction; i.e., at a tangent to the growth rings, so that the growth rings run parallel to the wide face. The wide surface of an edge-sawn board is sawn in the radial direction, i.e., along a radius between the pith and the bark, so that the growth rings run parallel to the narrow edge (Figure 4).

Shrinkage across the grain does not occur to the same extent in all directions. Due to the restraining effect of some anatomical features acting in the radial direction, shrinkage in the radial direction is about half of the shrinkage in the tangential direction. It follows from this that if two identical size boards

are sawn from a log, the one flat-sawn and the other edge-sawn, and dried to the same moisture content, then:

1. the flat-sawn board will shrink twice as much in width as the edge-sawn board;
2. the edge-sawn board will shrink twice as much in thickness as the flat-sawn board.

Such differences in shrinkage are the most common causes of warp in sawn lumber as shown in Figure 5. A flat-sawn board, which is allowed to dry without any means of holding it flat, will tend to cup away from the heart side. This is because the growth rings are more parallel on the sapwood side; therefore more tangential shrinkage takes place on this side of the board than on the heartwood side. Another example is round dowelling sawn from green wood which tends to become oval due to twice as much shrinkage developing in the tangential direction than in the radial direction. Third, a square piece of wood with sides truly flat-sawn and edge-sawn will shrink to become rectangular in shape. However, if the growth rings run diagonally across a pair of opposite corners, then the difference in shrinkage will cause the square section to become diamond shaped.

The size of the cross-section of sawn lumber influences the amount of shrinkage that develops. In general, pieces of larger cross-section shrink proportionately less than those of smaller cross-section. This is due to the outer zone of large-section lumber drying while being prevented from shrinking by the large central core of wetter unshrunk wood. In thin cross-sections, the surface and the inner zone of the wood tend to dry at similar rates and, therefore, they shrink together. Since neither zone restricts the other from shrinking, the total shrinkage in thin cross-sections is proportionately more than in thick cross-sections.

### Effect of Extractives

The presence of extractive materials in the cell walls of some species, such as western red cedar, will result in a lower than average fiber saturation point and lower than expected shrinkage values. This is because the extractives "**bulk**" the cell walls, restricting the amount they shrink when water is removed.

### Shrinkage of Specialized Wood Types

*Knots*

Knots have a much greater density than the surrounding wood and as a result, their shrinkage ratio is much greater. In addition, since a radial dimension of a knot is parallel to the longitudinal axis of a tree, the difference in shrinkage ratios is particularly large. The result is a high shrinkage stress at the periphery of knots. In a loose or encased knot, separation occurs and the knot may fall out. In intergrown knots, however, separation cannot readily occur and the knot will check under excessive drying stresses.

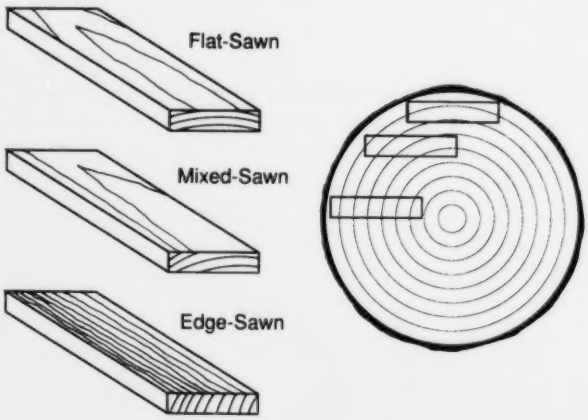


Fig 4 Grain direction in boards sawn from different locations in a log

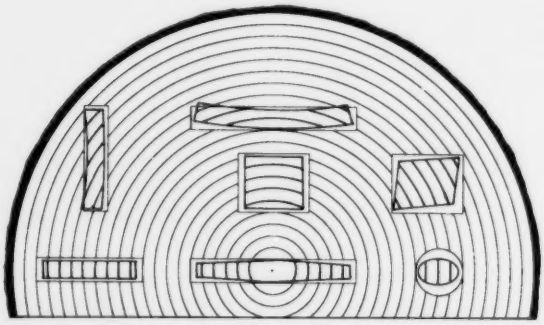

Fig 5 Shrinkage and warp of boards and mouldings as affected by the direction of grain

*Compression Wood*

In compression wood cells, fibrils are aligned at an angle to the cell wall. Therefore, during drying below fiber saturation point these cells shrink significantly in length. Normally, compression wood is not so extensive in a tree that lumber of pure compression wood can be cut. Rather, such lumber will contain compression wood on or near one or more surfaces. The unbalanced shrinkage that occurs in drying may result in the lumber being bent or twisted to such an extent that it has no commercial value. Particularly where only a small proportion of a piece of lumber is compression wood, these stresses may be so high that the compression wood portion will break in tension and will be seen to be broken at intervals along its length.

*Tension Wood*

Even though the function of tension wood in hardwoods is the opposite to that of compression wood of softwoods, it also has

the characteristic of high longitudinal shrinkage, although to a lesser degree than compression wood. Where excessive shrinkage of tension wood occurs it is associated with collapse in many kinds of wood.

*Juvenile Wood*

Since juvenile or core wood is formed during the first several years of the life of a stem, in fast-growing trees a substantial part of the center of the stem may be juvenile wood. Such wood is characterized by a large fibril angle and excessive longitudinal shrinkage. As a result, lumber from such trees is prone to excessive bow, crook and twist during the drying process.

*Curly Grain*

Wood with spiral, diagonal, or curly grain may also show excessive longitudinal shrinkage, owing to a transverse-shrinkage component along the length of the piece. Thus, if all the fibers ran through a board at an angle of 45°, it would tend to shrink in the same proportion lengthwise as edgewise.

# CHAPTER 3

# Determining Wood Moisture Content

## Oven-Drying Method

The standard way of determining wood moisture content is known as the oven-drying method. This direct method provides a very accurate measure of wood moisture content over the entire moisture range from fresh green wood to kiln-dried. This method also serves as a standard against which a number of indirect moisture measuring systems can be calibrated and compared.

As an example assume that the average moisture content of a board is to be determined. The following are the step-by-step procedures:

1. Cut and discard about 2 feet from each end of the board. This is done to eliminate the possibility that drying has already occurred from the ends of the board.
2. Cut a section about 1 inch long from each of the freshly cut ends. These sections, which will be used for moisture content determination, should be free of knots, rot, pitch pockets or any other imperfections (Figure 6).
3. Remove all loose splinters and sawdust from the sections.
4. Weigh the sections immediately and record these measurements as original or green weights. If there is a delay before weighing, the sections should be tightly wrapped in a plastic bag.
5. Place the sections in a ventilated oven at 215 to 220°F (102 to 104°C) and allow them to dry to constant weight. Normally this will require 18 to 24 hours.
6. Immediately reweigh the sections and record the measurements as the oven-dry weight.
7. Apply the method shown earlier to calculate the moisture content of each section, example:

Section 1 Original Weight = 80 grams

Oven-Dry Weight = 47 grams

Moisture Content = $\frac{80 - 47}{47} \times 100\% = 70\%$

Section 2 Original Weight = 101 grams

Oven-Dry Weight = 54 grams

Moisture Content = $\frac{101 - 54}{54} \times 100\% = 87\%$

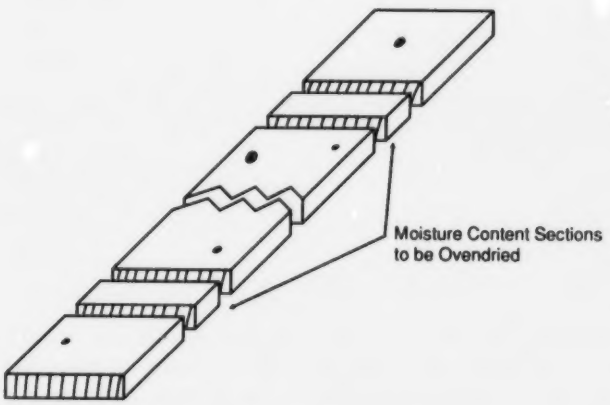


Fig 6 Preparation of moisture content sections

Since the moisture sections were taken from opposite ends of the board, the average of the two moisture contents (78.5 percent) can be used as an estimate of the average moisture content of the board.

## Electrical Method

For industrial use, the oven-drying method for moisture content determinations is often too time consuming and wasteful of material. Fortunately, there are portable electric moisture meters easily operated by one person, which provide very rapid assessment of moisture content. These meters use an electrical property of wood which varies with moisture content, such as electrical resistance, dielectric constant or radio frequency power loss. In Western Canada the electrical resistance method is used almost exclusively. Resistance-type meters are offered by several manufacturers but all employ the same principle of operation.

The operation of the resistance-type of meter is based on the fact that oven-dry wood is an excellent electrical insulator; that is, the wood has a very high electrical resistance. The resistance decreases rapidly as the moisture content of the wood rises towards fiber saturation point (25 to 30 percent moisture content) after which point there is little further change in resistance.

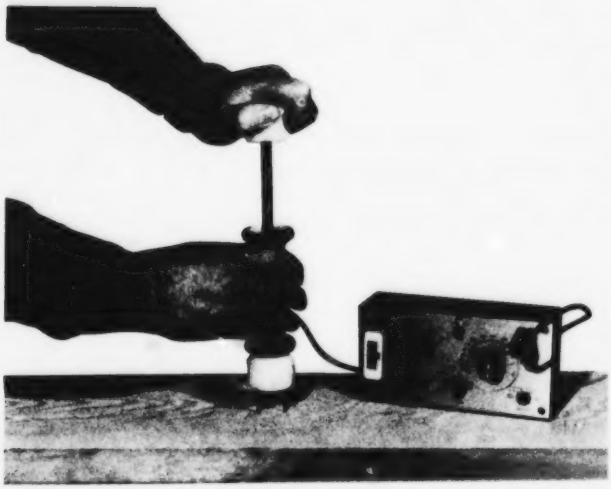

Fig 7 Resistance moisture meter and electrodes

Fig 8 Hand-held resistance moisture meter with short electrodes

A resistance meter is designed to measure the electrical resistance between two points in a piece of wood. The resistance is usually measured between two electrodes or needles which are driven into the wood so that the electrodes are aligned along the grain of the wood (Figure 7). Electrodes are usually mounted on convenient handles which allow them to be driven into and withdrawn from the wood with little effort. For smaller units short electrodes are mounted directly on the meter (Figure 8).

To make a reading, the electrodes are driven into the wood parallel to the grain, the "read" or "on" button is pressed and a value is shown on the scale or digital display. This value however, should not be assumed to be the moisture content since both temperature of the wood and the species affect the reading obtained and must be adjusted for accordingly.

The temperature of the wood being tested affects the reading given by the meter because at any given moisture content, the resistance in the wood falls as the temperature increases. Usually the reading given by the meter has been calibrated for a wood temperature of 70°F and, if the wood temperature is higher or lower than this, then a correction must be made. It is therefore necessary to know the temperature of the wood being tested and then correction tables can be used to correct the readings.

A convenient method for measuring wood temperature is to insert a temperature sensing probe, or thermocouple, into a hole made by the moisture meter needles and read the temperature directly on the temperature meter (Figure 9).

The electrical resistance of wood varies with species probably due to differences in wood structure and electrolyte concentration. Correction factors have been developed for all western, commercially important softwoods and are also available for some hardwoods.

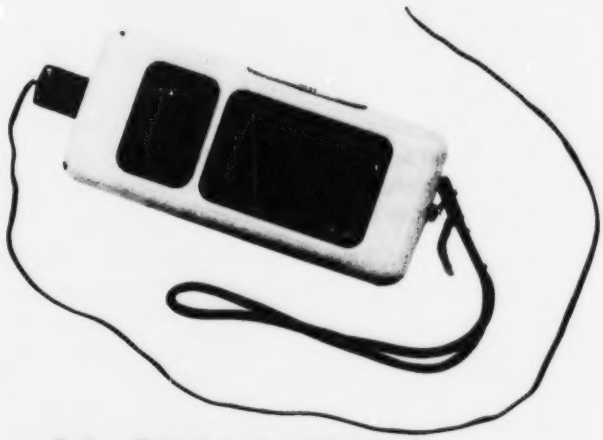

Fig 9 Temperature meter and thermocouple

If both species and temperature correction tables are available, the meter readings should be corrected first for temperature and then for species. Tables have been prepared which give combined species- and temperature-corrected values and this simplifies the process considerably. An operator can now find, in one step, the corrected moisture content corresponding to the reading obtained from the meter.

Another source of error arises if the resistance meter is used on wood which has been treated with preservatives. The chemicals in the preservatives change the electrical resistance of the wood and, depending on their quantity and distribution, the meter readings can be severely affected. Since it is impossible to determine the concentration of chemical at the point of measurement, moisture content readings are very unreliable.

Needle electrodes can be of two main types, insulated and uninsulated. Insulated electrodes can be of any length and

their identifying characteristic is that they are coated with a non-conducting lacquer along their length except for the tip or final one-eighth inch. The result of this is that the resistance and, therefore, the moisture content is measured only between the electrode tips. As the pair of needles is driven into the wood for varying distances, the moisture content at various depths can be determined.

In most instances when wood has recently been removed from a kiln, the moisture in the wood is not evenly distributed. Typically, a moisture gradient exists with moisture content being lowest at the surface and increasing towards the center. This distribution can be accurately detected by using insulated needles long enough to penetrate to mid-thickness of boards. If uninsulated needles are used, the moisture content indicated will always be that of the wettest wood between the electrodes, at whatever depth this occurs. This is because the electrical resistance is lowest in wet wood, and the small electric current flowing between the electrodes will always follow the path of least resistance. If for example the surface of kiln-dried wood is temporarily wetted by rain, then irrespective of the length of uninsulated needles, the meter will always read a high moisture content. If insulated needles had been used, the operator would have seen a high reading as the needles penetrated the surface layers of the wood, but the reading would have fallen rapidly to a lower reading, as the uninsulated conducting tips were driven in towards the center of the board.

If the meter is switched on continuously while measurements are being made, then readings must be taken immediately after the electrodes are driven into the wood. It is better however, if the meter is switched on only after each insertion of the electrodes. These practices avoid an error caused by drifting of the indicator needle in the meter.

The range of moisture contents which can be reliably measured with this type of meter is between 6 and 25 percent. Below 6 percent the resistance is too high to measure easily, and above 25 percent there is too little change in resistance to permit accurate measurements. Some meter scales extend beyond 25 percent but this is only to permit temperature corrections up to the fiber saturation point and do not imply accuracy of readings beyond this limit.

To avoid errors introduced by end-drying, meter readings should be made not less than 2 feet from one end of a board. Needles are inserted along the grain at mid-width of the face of each board to be measured. Standards do not define the depth of penetration but common practice is to drive needles to about one-quarter to one-fifth of board thickness to obtain an average for the cross-section. This assumption has less validity with high-temperature, fast-dried wood and is very unreliable for wood that commonly has wet pockets or streaks.

Continuous or in-line moisture meters for large volumes of wood are discussed under "Preparing Lumber for Drying" (Chapter 9) and "Quality Control" (Chapter 12).

# CHAPTER 4

# Factors Affecting Drying

The various forms of water in wood (water vapor, bound water and free water) have been described. In the drying of lumber these forms of water move to the surface by quite different mechanisms and by different flow paths. Depending on the conditions which exist in the wood, water may be converted from one form to another during this migration. For example, green lumber at ordinary temperatures contains about 30 percent of its dry weight as bound water, a negligible quantity of water vapor, and the remainder of the moisture as free water. For a wood-like spruce, with an initial moisture content of about 60 percent, roughly half the moisture will be bound water and half free water. For alpine fir, with 90 percent initial moisture content, there will be twice as much free water as bound water. In drying, the free water of the surface layers is the first to be removed. As a result, the moisture in the surface layers soon consists almost entirely of bound water, with a very small quantity of water vapor. Moisture moving from the core is converted, in turn, to bound water and then to water vapor, in which form it escapes.

## Vapor Diffusion

Water vapor moves by diffusion. In this process, molecules move in a random manner in all directions. If a high concentration of molecules occurs in one area and a low concentration in another, more molecules will leave the high-concentration area than will enter it and its moisture content will be reduced. Similarly, if molecules are being captured, condensed or removed from another area, more molecules will diffuse in than out, and there will be a net movement in that direction. The rate of vapor diffusion is thus proportional to the difference in concentration of diffusing molecules or, more precisely, is proportional to the difference in vapor pressure. The vapor pressure within moist wood increases with increasing moisture content up to the fiber saturation point; thus, while drying is taking place a **vapor pressure gradient** will exist from the zone within the wood which is at or above the fiber saturation point to the wood surface. There will be no significant vapor pressure gradient within the zone that is above the fiber saturation point. This means that within the zone above the fiber saturation point, no significant vapor movement is taking place.

Since there must be a continuous flow path available to permit vapor to diffuse from one zone to another, pure vapor diffusion is only effective in permeable wood.

**Permeability** results from the presence of connecting passages between wood cells. It is not related to hardness or strength, but only to the openness of these connecting passages. Liquids and gases move through permeable wood at rates which permit rapid drying. In impermeable wood, most or all passages are blocked, so that movement of liquids and gases is obstructed. Vapor diffusion must then operate in conjunction with bound water diffusion. Examples of permeable woods are ponderosa pine and many of the hardwoods of western Canada (alder, maple and birch). The sapwood of most species is permeable, but the heartwood of most western softwoods is much less so. Heartwood of western red cedar and alpine fir is impermeable, that of lodgepole pine is semi-permeable, while that of white spruce and western hemlock may be considered semi-permeable to permeable.

## Bound Water Diffusion

The movement of bound water through the cell walls is also a diffusion process. As in vapor diffusion, there are fewer molecules leaving the drier sites and more leaving the wetter sites. Consequently, there is a general migration from the wet to the dry parts of the wood. Since the wood surface is usually driest because of evaporation, there is a migration from core to surface and a **moisture gradient** exists.

The force responsible for bound water diffusion is the same as that for vapor diffusion, the vapor-pressure gradient. Bound water diffusion is a much slower process than vapor diffusion even though driven by the same force.

## Combined Bound Water and Vapor Diffusion

During drying neither bound water nor vapor diffusion acts alone. In moving from the core to the surface of the wood most moisture passes in sequence through the cell walls by bound water diffusion, evaporates into the cell lumen, passes across it by vapor diffusion, is absorbed by the next cell wall, passes through by bound water diffusion, and so on until the wood surface is reached.

When drying takes place from the ends of lumber the migrating moisture must pass through fewer cell walls, and the greater part of its migration is through the cell cavities by the

much faster process of vapor diffusion. Consequently, drying through the ends is much faster than drying through the sides of a piece. Since dense wood contains a much higher ratio of cell wall to cell lumen than low density (light) wood, and since bound water movement through the cell walls is slower, the rate of drying below the fiber saturation point in dense woods is much slower than in light woods. The greater resistance to drying of dense wood can result in a much greater moisture gradient being formed and much greater shrinkage stresses being developed so that the possibility of degrade in dense hardwoods is much more than in most softwoods.

## Free Water Movement

Free water in wood moves in response to capillary forces created by the evaporation of water from the surface cells. These forces exert a pull on the free water in zones below the surface. The most important factor affecting capillary flow is the permeability of the wood. Capillarity requires the least energy and is the most rapid form of the various flow mechanisms. This is the major reason why moisture-laden permeable sapwood normally dries at a more rapid rate than heartwood.

Capillary flow is at least 50 times faster in the direction of the grain than across it, because bordered pits or other obstructions (which are bottlenecks, even in permeable woods) are encountered much less frequently.

Free water movement can only occur where free water is present; that is, above the fiber saturation point. But it also requires the presence of enough moisture to provide a continuity of water reaching from the surface or evaporating zone to the zones below. Consequently it is faster at higher moisture content.

A further factor affecting capillary movement is the wood temperature. At higher wood temperatures the viscosity of water is reduced so that under a given capillary pull, the water will flow more rapidly. A rise of wood temperature from 70°F to 210°F reduces viscosity by a factor of three.

## Mass Flow

Another drying process is **mass flow** during high temperature drying. When lumber at a moisture content greater than the fiber saturation point is heated above the boiling point of water, some of the water is converted to steam at a pressure above atmospheric. If the lumber is of a permeable wood, the steam escapes due to the pressure differential and the lumber dries. If the lumber is of an impermeable wood, drying can take place only by diffusion, although at this temperature it is a fairly rapid process. Because steam generated in wood heated above the boiling point may have enough pressure to split wood, the use of high temperatures to dry an impermeable wood will usually result in severe degrade and should therefore, be avoided.

## Physical Elements of Drying

### Heat and Temperature

The main reason for using heat in drying is to provide the energy required to evaporate the moisture present in the wood, 1000 Btu or more being required to evaporate each pound of water present. An additional reason however, is to raise the temperature of the lumber, since the movement of moisture, either by capillary flow or diffusion, is more rapid at high temperatures. To produce the same rate of diffusion at 120°F as at 160°F (or say, 50°C and 70°C), a much lower humidity will be required and a steeper moisture gradient will result. This in turn increases the possibility of degrade in the lumber. Increased temperature, therefore, increases the rate of moisture movement so that a high humidity may be maintained without unduly slowing the rate of drying.

Wet wood is more plastic at high temperatures and, because of this increased plasticity, it yields more readily to any stress imposed. However, whether wet or dry, wood is weaker at higher temperatures. Wood may be more prone to checking and splitting at higher temperatures although this has not been determined with certainty.

When the surface of lumber contains free water, the temperature of the wood is the same as that of the wet bulb and will stay at that temperature as long as there is sufficient moisture movement to keep the surface moist. When the free water at the surface is evaporated, the moisture content of the surface approaches the **equilibrium moisture content**; concurrently, the temperature of the wood surface increases and approaches the dry bulb temperature.

### Humidity

The equilibrium moisture content of lumber is determined largely by the relative humidity in a kiln. Therefore, to avoid excessive surface shrinkage and consequent drying defects, the relative humidity should be kept at a high value. On the other hand, high relative humidities reduce the difference in vapor pressure between the dry and wet bulb temperatures and, consequently, reduce the rate of drying. A practical choice of relative humidities is a compromise between a high value for a low degrade loss and a low value for rapid drying. As the kiln humidity increases due to evaporation from the lumber, provision must be made to remove the excess moisture. This is usually done by discharging some of the kiln air through roof-mounted vents.

### Circulation

To perform effective drying, a uniform movement of air is necessary to carry heat to lumber and to carry evaporated moisture away. This circulating air must pass over the surface of the boards being dried. Any air that misses a pile of lumber accomplishes no drying.

Since the air is cooled and becomes wetter as it picks up moisture, its ability to dry the lumber becomes progressively

less as it passes through a load. By increasing the air velocity, the lumber near the exit side of a load receives hotter, drier air than it otherwise would. Not only will this result in faster drying of the lumber at the exit side, increasing the average rate of drying and reducing the drying time, but it will also result in higher surface transfer rates and more uniform drying of a load. These advantages must be measured against the increased cost of power to attain the greater air velocities.

At the beginning of drying, a considerable amount of water is being evaporated and, as a result, the drop in air temperature across a load is very high, and the humidity of the air increases almost to the saturation point. Under these conditions, for rapid drying the air velocity should be high. On the other hand, when the surface of the lumber has been dried below the fiber saturation point, the rate of evaporation is reduced. Under these conditions, a much reduced air velocity is acceptable. For these reasons use of variable-speed fans is advantageous.

# CHAPTER 5

# Drying Defects and their Control

The drying of wood by all practical methods presently used is accompanied by shrinkage. In itself shrinkage is not a defect but most drying defects are a direct result of shrinkage and the resultant stresses. It is important to understand how the stresses develop, the problems they cause and the measures necessary to minimize damage to the wood.

## Stress Development

When a very thin (less than 1/2 inch thick) piece of wood dries, it does so quite uniformly, so that all of the piece dries and shrinks together. No shrinkage problems should be encountered. With thicker lumber however, drying proceeds more or less layer by layer, with the outer faces and edges drying first and this dry zone gradually moving towards the center of the cross-section of a piece.

An important stage is reached when all of the free water in the outer layers, referred to as the shell, has gone and removal of bound water begins here, while the center or core still contains free water. At this point, the shell wants to shrink, but it is prevented from doing so by the core that is still in its wet, swollen state. Drying of the shell proceeds, but shrinkage is prevented. The result is a dry shell that is larger than it would have been if it had been able to shrink in the normal fashion. The shell therefore, is in a stretched condition and is described as being in **tension**. The core on the other hand, is being squeezed by the shell that wants to shrink and it is said to be in **compression**.

The shell of the dried wood will retain its stretched condition and, although it will shrink or swell according to changes in moisture content of the atmosphere where it is placed, it will always be larger than it would have been if shrinkage had taken place unhindered. This piece of wood would then be described as being **set** in a stretched condition and the shell is referred to as being in **tension set**.

Similarly, the wet core of the wood that is now being compressed can take on a **compression set**. Later when it does shrink as it dries it will shrink more than it would have if allowed to dry without being squeezed by the outer shell.

## Casehardening

### Development of Casehardening

Casehardening is a term used to describe a particular distribution of stresses which are found in lumber after drying. It is important to follow the step-by-step development of casehardening as it develops during drying so that appropriate measures can be taken to correct it where necessary.

Fig 10 Cupping due to resawing board that is casehardened

In the early stages of drying the shell is restricted from shrinking by the non-shrinking core that is still above fiber saturation point. The shell therefore, is in tension while the core is in compression. Ultimately, a tension set develops in the shell and a compression set develops in the core.

Later in drying the core begins to dry below fiber saturation point and it therefore begins to shrink. If compression set had developed earlier then the shrinkage of the core will tend to be greater than it would have been otherwise. When the core begins to shrink, it is at first aided by the shell which had been stretched while trying to shrink. The shrinkage of the core is said to relieve some of the tension stresses in the surface layers. However, as the core continues to shrink as it dries, it is prevented from doing so by the shell which has a tension set; that is, the shell is fixed in a stretched condition.

The stresses start to reverse at this point; the shell goes from a stretched condition to a tendency to be pulled by the core, and it therefore becomes compressed or goes into compression. The core goes from a compressed condition to being pulled by the surface shell and it therefore goes into tension.

This condition is known as **casehardening**. The surface is in compression and the core is in tension. If the surface and the core could be separated at this point the surface would enlarge and the core would shrink.

This in fact can happen in the normal manufacturing process. The casehardened condition is the normal result of kiln-drying but the severity of the condition can be influenced by the drying conditions which are used. If a board in this condition is sawn lengthwise, parallel to the wide faces, the two halves will cup towards one another (Figure 10). This is because the two outside faces will enlarge and the two new faces (formerly

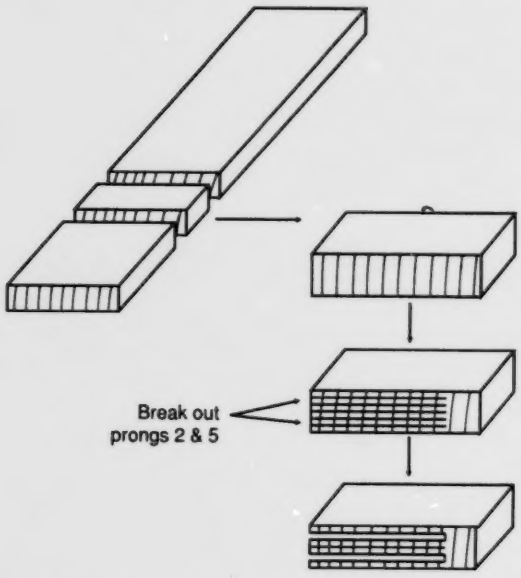


Fig 11 Preparation of samples for casehardening test

the core of the single piece) will shrink and cupping will result.

Therefore, in any manufacturing process which involves sawing lumber lengthwise or removing substantially more from one side of a piece than from the other, problems can be anticipated. Casehardening is seldom a problem with kiln-dried framing lumber since this is seldom sawn along its length and, therefore, a balance is always maintained between the compression stresses in the shell and the tension stresses in the core.

## Detection of Casehardening

When it is known that lumber is being dried for further manufacturing processes, it is wise to check how great the imbalance is between shell and core stresses. The usual method used for detection begins by sawing a strip about 1/2 to 1 inch long in the along-the-grain direction at least 18 inches from the end of a board from the kiln charge being dried. If the strip is cut from nearer the end than 18 inches, stresses will probably not be found, since most of the drying here has occurred along the grain, and smaller differences in moisture content between shell and core have developed.

Each strip is then slotted by a number of saw cuts running from one edge parallel to the original board faces. The cuts are stopped about 1/2 inch from one end to hold together the prongs so formed. These steps are indicated in Figure 11. For nominal 2 inch lumber, five cuts should be made so that six prongs of equal thickness will be formed. Prongs number 2 and 5 should then be broken out and the movement of the

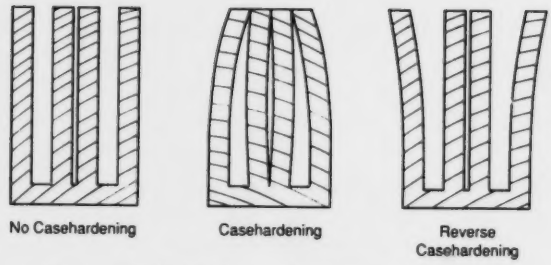


Fig 12 Examination of prongs for presence of casehardening

remainder will give a true indication of the pattern of stresses within a board.

Next, to eliminate any shrinkage stresses which are due solely to moisture content differences between the shell and core, the sets of prongs are allowed to stand for one day in a warm room, during which time all of the wood will come to a uniform moisture content. The condition of the prongs will now give a precise indication of the presence of casehardening as indicated in Figure 12.

The saw cuts allow each prong (which represents a layer of wood across the cross-section) to move according to any stresses present. Wood that is in tension contracts and wood that is in compression expands. If the prongs are straight at this time, it indicates that there are no casehardening stresses present and the lumber can be resawn and manufactured with no danger of warp developing due to stresses.

If the outer prongs tend to lengthen and turn in and the inner prongs shorten, then this indicates casehardening that must be removed before lumber is further manufactured.

## Preventing and Relieving Casehardening Stresses

Casehardening originates in fast-drying and the rapid development of a large moisture content difference between shell and core. The tendency towards casehardening is greater in thick lumber than in thin lumber, in impermeable slow-to-dry species than in permeable ones, and in rapid forced drying conditions than in slower drying conditions.

In order to minimize the development of casehardening, an operator must try to keep the surface of the wood at as high a moisture content as possible without excessively slowing the rate of drying. In effect, this means drying in humid conditions rather than in very dry conditions.

If, at the end of the drying period, it is found with the prong test that an excessively severe casehardening condition is present, so that further manufacturing processes would be difficult, then a special stress-relief treatment must be given. The basis of this treatment is that wood becomes more plastic (soft) if its temperature and moisture content are raised. When

the wood is made more plastic it can yield to any stresses present and the stresses can then even themselves out.

In practice this treatment is applied by raising the temperature and humidity in the kiln. This is frequently done by simply allowing saturated steam to enter the chamber. The end point in the treatment is rather difficult to determine and a real danger exists if the process is continued too long.

Consider lumber with a casehardened condition at the end of drying, the shell is in compression while the core is in tension. When surrounded by very moist air, the dry shell absorbs moisture rapidly and it tends to swell, but it is prevented from doing so by the core that has not yet been affected by the increase in temperature and humidity. If this situation persists, whereby the surface tries to swell but cannot do so due to the shrunken core, then the surface will develop **compression set** at a fairly high moisture content. In other words, the shell has increased in moisture content considerably, but it is still restrained in its shrunken state.

Assume now that the supply of moist air is turned off and the operator finds that the lumber has gained so much moisture that some redrying has to be done to reduce moisture content to the desired level. During redrying, the shell starts to shrink and because it is in compression set it has a higher than normal tendency to shrink but this excessive shrinkage is prevented by the core, so the shell goes into tension.

The result of too much stress relieving is to reverse the stresses that were present, so that now the shell is in tension and the core is in compression. When stress prongs are cut the outer ones fan outwards since they are now free to shrink and the inner ones are free to lengthen (Figure 12). This condition, which is known as **reverse casehardening**, is very serious because it cannot be removed unless the wood is completely soaked and drying begun over again.

For this reason, stress relief is a treatment that requires much attention from a kiln operator. When drying the same species and sizes by the same drying conditions, it will soon become apparent how long the treatment must be continued. When starting with new species or thicknesses of lumber, it is important to be cautious and, therefore, the prong test should be used regularly to determine the correct procedure.

Kiln temperatures and humidities for stress relieving or conditioning treatments will be covered in Chapter 10 dealing with kiln schedules.

## Checking

In the description of casehardening, much was said about drying stresses caused by unequal shrinkage. If the stresses are so severe that the wood cannot withstand them, then wood failure will occur in the form of a check or split. A check may be defined as a separation, formed during drying, of the wood cells extending longitudinally along the length of a piece.

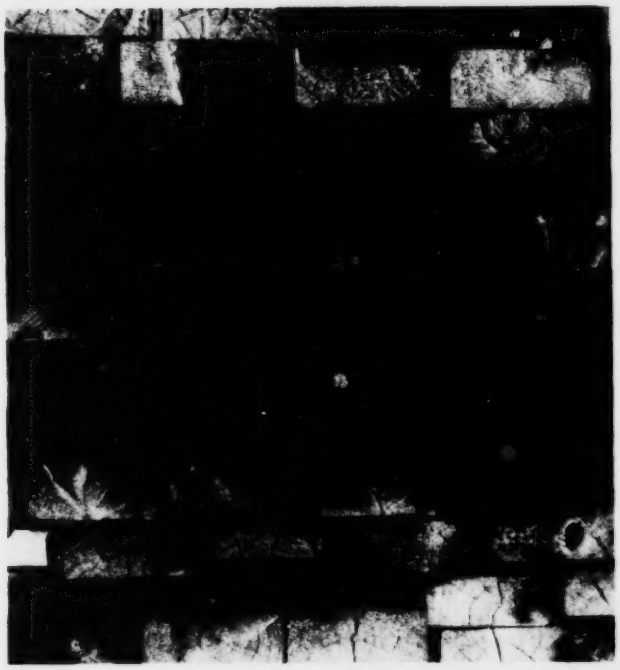

Fig 13 End checks

Depending on how and when the stresses due to unequal shrinkage develop, different kinds of checks can be found. Unequal shrinkage has three principal causes:

1. As described in relation to casehardening, the difference in shrinkage between shell and core during drying.
2. The difference in shrinkage in the radial and tangential directions of the wood.
3. The difference in the directions of shrinkage between normal wood and reaction wood.

In general, checking is caused by unequal shrinkage in adjacent areas of wood.

The following are the principal types of checks:

### End Checks

End checks (Figure 13) are caused by too rapid drying of the ends of boards. Wood dries more rapidly along the grain than across it and this effect extends for up to 18 inches in from each end of a board. Obviously drying is most rapid at the extreme ends. The ends, therefore, tend to shrink much sooner that the remainder of the piece which will resist the shrinkage, thus placing the ends into tension. If the tension stresses are greater than the strength of the wood, then checking will result.

One solution to this problem is to coat the ends with a moisture resistant coating, thereby slowing down the drying and the shrinkage. While this is economically feasible with large

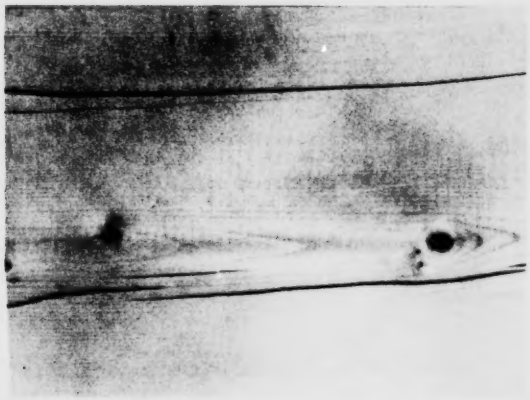

Fig 14 Surface checks

Fig 15 Internal checks

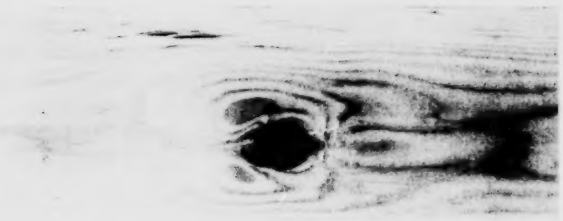

Fig 16 Damaged or loosened knot

or valuable timbers, it is generally not done when drying softwood dimension lumber. Rather, the common practice is to trim back the ends to remove the end checks. End trim is one of the most serious losses in the production of kiln-dried dimension lumber.

Another approach to reducing these losses is by taking great care in the construction of stickered loads of lumber being placed in a kiln. Loads should be constructed so that no ends protrude, the outermost stickers should be flush with the ends of the lumber. In this way air circulation will be impeded at the ends of the boards so that the drying rates and shrinkage rates will be reduced.

End splits are more common in flat-sawn boards because width shrinkage in flat-sawn boards is about double that in edge-sawn boards.

### Surface Checks

Surface checks of lumber (Figure 14) are caused by the surface layers drying and shrinking faster than the core. As described under casehardening, early in drying tension stresses develop in the shell and, if these are greater in magnitude than the strength of the surface wood, then checks will develop. Surface checking is more common in the early stages of kiln-drying than in later stages because, when the moisture content is higher, the wood is weaker and less capable of withstanding stresses.

Surface checking is more likely to occur in flat-sawn boards, since shrinkage across the width of flat-sawn boards is about double the shrinkage across edge-sawn boards. The difference in shrinkage between a drying surface and a still swollen core will, therefore, be correspondingly greater.

Generally, surface checks formed during the early stages of drying will close as drying proceeds and the inner layers start to shrink. The checks become almost invisible on the surface of boards and very difficult to detect. Sometimes they close on the surface, but penetrate below the surface to become a form of internal check.

Since it is not practical to dry lumber without having the surface layers substantially drier than the inner layers, stresses must inevitably be set up in the wood. Successful drying of wood free of surface checks requires control of the rate of drying to minimize moisture content differences between shell and core.

### Internal Checks (often known as "honeycomb")

Apart from the instance noted above of internal checks arising from an extension of surface checks to the core, internal checks (Figure 15) arise from internal tension stresses.

As drying continues beyond the initial stages, progressing layer by layer from the surface inwards, the core eventually dries below fiber saturation point and tends to shrink. Shrinkage of the core is restricted however, by the outer shell which was forced to dry in an enlarged condition (shell tension set in the initial stages of casehardening). A tension stress therefore, is set up in the core and, again if this stress is greater than the strength of the wood, wood cells will tear apart and internal checks will result.

The prevention of internal checks is based upon not creating too great a moisture-content gradient between the shell and the core for those species and sizes which are known to be prone to internal checking.

### Knot Damage

Lumber can be downgraded if knots check, become loose or fall out leaving holes (Figure 16). In some species, for example in Douglas-fir, knots may be encased in resin and, if too high drying temperatures are used, the resin becomes

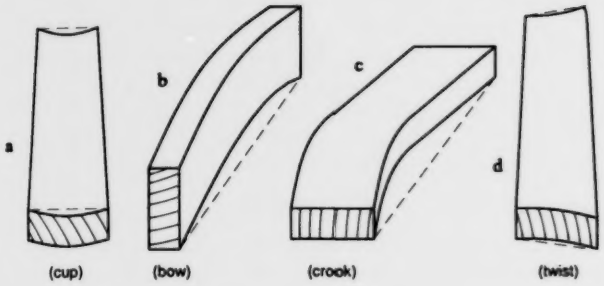


Fig 17 Four common forms of warp

brittle and is broken up in the planer allowing knots to fall out. Knots shrink faster than the surrounding wood because they dry from their end grain, and check because of differences in shrinkage parallel to and across the annual rings within knots. Damage to knots can only be prevented by slow drying and by targeting as high a moisture content as allowed in order to minimize shrinkage.

### Warp

Warp may be defined as any form of distortion which occurs during milling or drying of lumber. It may occur because of differences between radial, tangential and longitudinal shrinkage in the piece as it dries. Warp is also increased by wavy or distorted grain and the presence of compression wood, tension wood or juvenile wood. The common forms of warp are:

*Cup*

Cup is the shape taken when a board develops a curvature across the grain (Figure 17a). Flat-sawn lumber has a natural tendency to cup when drying, since shrinkage is greater on the face which is most parallel to the growth rings; that is, on the sapwood side. Cupping is also the distortion which results from ripping casehardened lumber since the inner surfaces contract and the outer surfaces expand. If boards dry more from one face than from another, cup is likely to occur due to greater shrinkage on the drier face. Therefore, the practice of drying wide, 1 inch lumber with stickers between only every second row should be avoided. Adequate use of stickers to prevent board movement is the best prevention against cup. The greatest losses due to cup occur in planing since the pressure of planer rollers will cause splits.

*Bow*

Bow is the shape taken when a board develops a curvature along the grain, so that the wide faces become concave and convex in a longitudinal direction (Figure 17b). Bow is frequently due to the presence of reaction wood along one wide face, so that longitudinal shrinkage develops on one face only. Good sticker restraint will help to minimize this problem.

Fig 18 Severe collapse in western red cedar

*Crook*

Crook is similar to bow in that it is the shape taken when a board develops a curvature along the grain, but this time the narrow edges become concave and convex (Figure 17c). Crook is frequently due to the presence of reaction wood along one edge so that longitudinal shrinkage develops in that edge only. Stickers are less able to restrain movement in this direction hence the problem is largely unavoidable, but as with all shrinkage related defects, is made worse by overdrying.

*Twist*

Twist is the shape taken when a board develops a spiral-like distortion along the grain so that the four corners of any face are no longer in the same plane (Figure 17d). Twist can result when a spiral-grained log is sawn or when a straight-grained log is sawn so that lumber with diagonal grain is produced. This means that the length of wood cells runs at an angle to the edges and faces of a board instead of parallel to them. Normal shrinkage during drying, therefore, is slightly in the longitudinal direction and the board twists.

Twist is a particular problem in lumber sawn to enclose the pith since the wood nearest the pith, juvenile wood, often has spiral grain and has an unusually high component of longitudinal shrinkage. It is for this reason that twist is a problem in drying wood sawn from young trees or plywood peeler cores. Twist-prone lumber must be sawn to minimize thickness variation since good contact with stickers is essential to restrain movement during drying. A combination of high-temperature drying, closer sticker spacing and clamps or weights on the top of loads has been shown to almost eliminate the problem.

## Miscellaneous Drying Defects

### Collapse

**Collapse** is an abnormal type of shrinkage which distorts, flattens or crushes wood cells. The commonly accepted theory for explaining the phenomenon of collapse is as follows: in very wet wood, the cavities of a number of cells may be entirely filled with liquid free water, with no room being left for air. As these cells dry, air should enter the cell

cavities to replace the free water moving out. The passage of air through wet wood is very slow however, and the free water can pass out of the saturated cells faster than the air can enter. When this happens the cell walls are drawn together by capillary tension forces and they will buckle and fold to the extent that the cell cavity is completely closed. Note that it is not the external air pressure on the outside of the wood which is responsible for this collapse, but rather the cohesive force of the water pulling the wet cell walls together. The collapse of groups of many cells produces sunken areas in the surface of lumber giving a washboard effect and in thick lumber internal checks may also develop (Figure 18). In western Canada collapse is usually found only in some western red cedar which has a very high moisture content.

The main difference between collapse and normal shrinkage is that collapse occurs only in cells which are losing free water from the cell cavities and not from the cell walls, whereas normal shrinkage occurs only in cells whose cavities are empty of free water and whose walls are losing bound water. Therefore, collapse can occur only in cells above fiber saturation point and normal shrinkage can occur only in cells below fiber saturation point.

Cell walls become soft and plastic when wet wood is heated, collapse is therefore more liable to occur when excessively high temperatures are used in kiln-drying. If a particular species is known to be prone to collapse, then it is usual to air-dry its lumber before kiln-drying. If all of the drying is done in a kiln, then low temperatures not exceeding 120°F dry bulb are used until the moisture content has dropped to fiber saturation point and the danger of collapse is over.

### Raised Grain

The corrugated appearance of the surface of some softwood lumber, known as **raised grain**, usually develops when lumber is not dried to a uniform, low moisture content before it is planed. In flat-grain lumber corrugation of the surface is due principally to the planer knives crushing the hard latewood into the softer earlywood beneath it. Later due to mechanical springback or moisture pick-up, the latewood rises above the earlywood cells causing the rippled surface effect. In edge-sawn lumber that is planed when dry, but which then absorbs moisture, a corrugated surface is caused by greater swelling of the latewood bands above the earlywood bands.

### Loosened Grain

The defect known as **loosened grain** most frequently occurs on softwood lumber having very dense latewood, in which the shrinkage of the latewood in one annual ring is much greater than that of the earlywood in the adjacent ring. This difference in shrinkage may cause a plane of shear to develop between the two rings. The consequent separation of the annual rings will cause slivers to occur near the surface which when pulled, will often tear along the length of the board.

The occurrence of loosened grain is aggravated by the use of too low a relative humidity during the kiln-drying process. This does not mean that it will always cause loosened grain, but rather that certain classes of timber are prone to develop this defect under faulty drying conditions. In species prone to this defect, the pounding of the wood by improperly adjusted planer knives also can cause separation of the grain at the annual rings, particularly in wood in which there is a considerable difference between the density of earlywood and latewood. Excessive pressure on the feed rolls may also be responsible for this defect in such species.

### Fungal Stain

Surface molds and sap-staining fungi (blue stain) will develop in some softwood species, particularly pines, if the kiln conditions are set to provide too low temperatures (less than 110°F) and high humidity. **Sapstain** is caused by fungi growing on the wood surface, but can be prevented by rapid drying of the wood surface to reduce surface moisture, or by drying at temperatures over 140 to 150°F.

### Chemical Stain

Kiln-drying at high temperatures causes the wood of some species to appear "toasted".

Some of the brown-red to black discolorations which appear on lumber are associated with natural wood extractives and free moisture in the wood which react with iron to form dark-colored compounds. Whereas all commercial woods are subject to this stain, western red cedar is most susceptible followed by yellow cedar and Douglas-fir. Such discolorations may occur in kiln-drying where steam pipes develop leaks and permit rust-containing water to fall on lumber.

The **brown stain** that develops in white pine lumber darkens the wood to colors ranging from dull yellow to dark brown. It is most prevalent during hot and humid months and in logs that have been stored in water for long periods. The stain usually occurs in heartwood, especially in the vicinity of knots, at the junction of heartwood and sapwood or along lines of shake. Often it shows only at the surface of boards but in extreme cases it may penetrate deeply into the wood causing a condition that resembles minor charring. The stain is believed to be caused by enzymatic degradation of the contents of wood cells along with the reaction to heat in a kiln. For the latter reason it is sometimes referred to as "kiln burn".

A similar stain may also appear during the drying of amabilis fir which has been held in prolonged storage in the green condition. Naturally produced enzymes actively convert certain wood extractives to materials that can become colored by oxidation during the kiln-drying process. The extractives are carried to the surface during drying and deposited there as colored materials.

The incidence of brown stain can be lessened where the time intervals between felling of trees, skidding of logs and sawing of lumber are short and mild kiln schedules are used. The storage period of lumber between sawing and kiln-drying is most critical and should be kept to a minimum particularly if the lumber is bulk piled. Lumber kiln-dried immediately after sawing is usually free of this stain.

Chemical brown stain in white pine lumber can be practically eliminated if lumber is treated with a 0.5 percent aqueous solution of sodium fluoride immediately after sawing. Sodium azide also has been found effective but both chemicals require careful handling procedures. More recently, dipping of green lumber in an ammoniacal zinc oxide solution for 30 seconds, placing between stickers for a few hours and then close piling for seven days prior to kiln-drying has been found to produce stain-free lumber. The latter chemicals are cheap and of low toxicity to humans.

Stains ranging in color from orange to almost black, particularly on the ends of lumber, are often observed in western hemlock. They are concentrated in two main zones: the heartwood-sapwood boundary and the sapwood-cambium boundary. Chemical treatments of them are not always effective. Always confined to the lumber surface, these stains can be removed permanently by planing provided the lumber remains dry. Since the stain is innocuous, in no way connected with decay, sapstain or mold, and can be removed by planing, its presence may be ignored.

# CHAPTER 6

# Kiln Types and Equipment

A lumber drying kiln is a building or structure designed specifically for removing moisture from wood by evaporation. In its most usual form it functions by passing air controlled at particular levels of temperature and humidity over the surfaces of the lumber being dried. The essential features of a kiln are:

- ***Heat*** to evaporate moisture from the wood.
- ***Humidification*** to prevent the air from becoming too dry and thereby possibly cause surface damage to the wood.
- ***Ventilation*** to emit water-saturated air from the kiln and admit dry air.
- ***Circulation*** to move the air between rows of lumber to carry in heat and carry away evaporated water.

These features can be supplied in a number of ways and thereby provide a way of classifying kilns into different types. In addition, other features including the materials used for construction or the methods used for loading, can also be used to describe kilns.

## Structural Materials

Various materials are used to build kilns. Wood, concrete block, clay tile, reinforced concrete, concrete-asbestos panels, and insulated aluminum panels are all commonly used, with various vapor barriers to restrict vapor movement from inside the kiln, thereby keeping the structural materials dry.

### Wood

Wooden kilns were widely used for drying Douglas-fir and cedar and were serviceable for 20 years or more. When drying western hemlock however, service life was reduced to about 5 years. Investigations showed that the high acidity of the hemlock vapors released during drying were responsible. In addition, by providing protection from the weather on outside walls, these vapors were trapped within the sealed structure. Wood frame drying structures are often favored for dehumidifier kilns that operate at medium to low temperatures. In this application, as in conventional kilns, all interior wood or plywood sheathing should be protected with a vapor barrier.

### Aluminum and Steel

The corrosion resistance of aluminum in a kiln atmosphere, along with its excellent properties as a vapor barrier, has led to the development of the prefabricated aluminum kiln (Figure 19). Reinforced panels having aluminum inner and outer skins with fiberglass or foamed polystyrene insulation between, are bolted to an aluminum or steel frame set up over the prelaid foundation. Provision is made for thermal expansion and contraction of the walls by means of a mastic or rubber joint sealant placed between the panels. These panels may also be used effectively to replace sloped wooden roofs although they are unsuitable for flat roofs.

Although aluminum is extremely resistant to corrosion, it may still deteriorate if the interior skin of aluminum is broken or pitted, permitting vapors to pass into and condense within the panels. For this reason all panels should be sealed absolutely to prevent penetration of the kiln atmosphere. Roof panels should be laid on a slope to permit drainage of any internal condensation.

When two dissimilar metals (like aluminum and steel) are placed in contact in a liquid, they will form a "battery" whereby small electric currents are generated while one or both of the metals dissolves or corrodes. Such metals should be separated by a good electrical insulator. Contact between recorder capillaries and other metals will also provide a situation where corrosion can occur when wet. Aluminum should not be permitted to make contact with steel at any point where loss of heat will cool one surface below the dew-point temperature and thus permit condensation even for a short time.

A particularly serious form of corrosion takes place in kilns operated at high humidities where inadequately protected steel is placed in contact with the floor or other heat sink. For example, in the case of steel rails or steel columns embedded in the floor where they are cooled by contact with the ground, moisture may condense on them causing rapid corrosion. Consequently, steel should be protected by a suitable coating. Corrosion of rails may be reduced by embedding the entire rail except the upper inch in concrete and keeping the exposed part well lubricated or coated at all times to prevent contact with condensate.

Aluminum kiln rails have been shown to be totally resistant to corrosion in coastal hemlock kilns provided that steel fittings do not contact them. They should be flanged to the concrete floor with aluminum only.

### Concrete Block and Brick

Other common construction materials for kilns are concrete block and brick. These have the advantage of moderate cost,

Fig 19 Prefabricated aluminum kiln

but only fair insulating properties. Concrete block kilns are usually insulated but their construction does not usually allow for the continual thermal expansion and contraction associated with the wide ranges of temperature in operating (including unloading) the kiln. As a result cracks often develop in the walls. Vapor escaping through these cracks attacks the mortar and concrete, resulting in the development of larger cracks, falling out of mortar and spalling of concrete. Such construction must be properly protected by a vapor barrier and deterioration must be quickly repaired.

## Progressive and Compartment Kilns

Kilns can be categorized into two groups, the progressive kiln and the compartment or charge kiln.

### Progressive Kiln

In the progressive kiln, one form of which is shown schematically in Figure 20, the loads of lumber to be dried enter the green or loading end of the kiln and are moved progressively forward at given intervals until the dry or unloading end is reached. As each load is removed from the dry end, it is replaced by a fresh load at the green end. Air from the heaters normally enters the kiln at the dry end, exposing the driest load to the most severe drying conditions. As the air passes through the loads it is progressively cooled and becomes more humid, so that by the time it reaches the green end, drying conditions are relatively mild. This type of kiln generally uses relatively long drying times. They have never been widely used in western Canada but they have been popular in Scandinavia for drying softwood lumber.

### Compartment Kiln

A compartment kiln is completely loaded with lumber in one operation, the lumber remaining stationary during drying. Temperature and humidity are controlled to a predetermined schedule or to prescribed set-points and are reasonably uniform throughout the kiln at any time. When the lumber is dry the entire load is removed. The main advantage of this type of kiln is that since all lumber is loaded at the same time, drying conditions can be selected to suit the specific requirements of the species and products being dried.

## Kiln Loading

Most large kilns are loaded from the end, the loads of lumber being built on trucks running on rails installed through the kilns and loading and unloading area. Change-over time can be very short where a load on a track is pushed out one end of a kiln and a preassembled green load is pushed into the kiln immediately following.

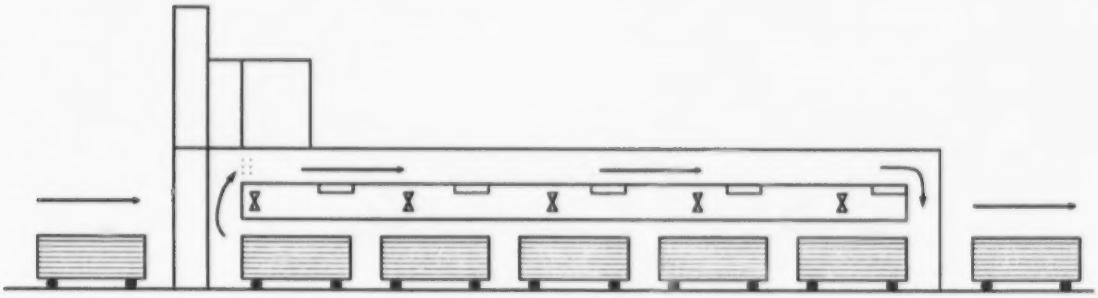

Fig 20 Progressive kiln with green lumber entering "Cool" end and dry lumber exiting "Hot" end

Fig 21 Forklift-loaded kiln

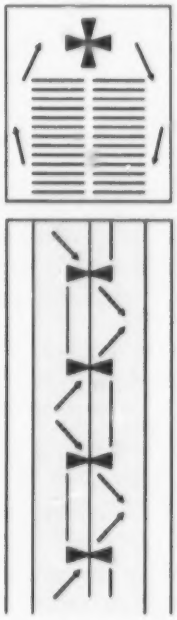

Fig 22 Air flow pathways in a line-shaft kiln

Many smaller kilns are loaded and unloaded from the sides by means of forklift trucks (Figure 21). Loads are placed on bunks on the kiln floor. A side-loading kiln has a longer change-over time than a track-loading kiln and particular care must be taken in placement of loads to ensure good air flow and uniform drying.

## Air Flow Systems

In order to dry lumber, air of controlled temperature and humidity must be passed over its surface. The air performs two functions: it carries heat energy to the wood to effect evaporation and also removes the evaporated water vapor.

Effective circulation of air involves several factors; the size, location and speed of the fans to drive the air; provision for reversal of air circulation; the installation and use of baffles to direct the air through the load; and the placing of stickers (spacers) within the load to facilitate the movement of air across each piece of lumber.

## Fans

In almost all commercial kilns, fan speeds are fixed and therefore cannot be varied for the material being dried nor at various times in a schedule. Recent developments in motor control now permit variation in fan speed and therefore air

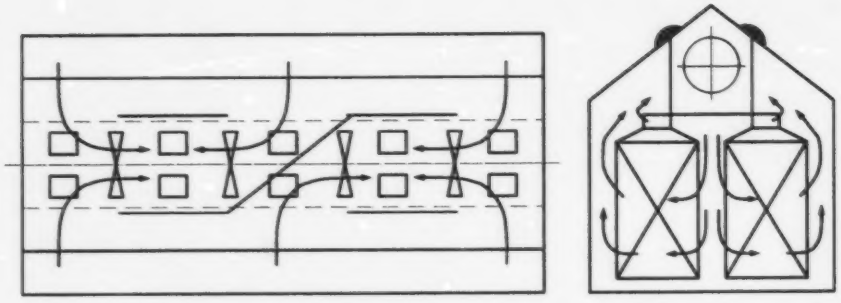

Fig 23 Single-air pass configuration of line-shaft double-track kiln

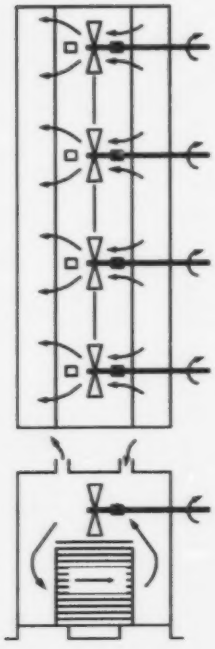

Fig 24 Air flow pathways in a cross-shaft kiln

flow rate according to the progress of drying of a load. For upgrading of existing fan systems, the following "fan laws" show the relationship between performance and requirements. For any specific fan:

1. the volume of air moved varies directly with the speed;
2. the static pressure varies with the square of the speed;
3. the horsepower varies as the cube of the fan speed, thus to double the fan speed requires eight times the horsepower.

All modern kilns utilize fans located within the kiln and almost always mounted overhead the lumber, with a false ceiling or deck located between the fans and the outside edges of the load. The fan arrangements are of two general types, line-shaft or cross-shaft.

### Line-Shaft Fan System

The line-shaft system was originally developed to move large volumes of air at low air speeds with a minimum of power. It is best suited for drying lumber of low initial moisture content and of slow drying rate.

In the traditional line-shaft arrangement (Figure 22) a series of disc fans is mounted on a shaft running the full length of the kiln. The fans are alternately a left- and right-hand design and are housed in a zigzag baffle system which directs the air across the kiln. The fans operate in either direction in order to allow reversal of air flow through the load. The drive motor is usually located in the control room at the end of the kiln or is housed outside of the kiln at one end. To increase shaft speed and achieve higher air circulation rates a split-shaft system is used where the shaft is cut at mid-length and a motor is placed at each end. A greater efficiency of air flow can be achieved through the use of propeller-type fans in place of disc fans.

In older double-track kilns it will be noted that air passes from the fan assembly through both tracks of lumber before returning to the fans. If, as in many kilns, there is only a single heat source (hot-air distribution duct, steam coils, etc.) located in the fan deck, air travelling through both tracks may lose much of its drying capacity, through losing heat and gaining moisture, before being reheated. An alternative arrangement of a line-shaft system is to direct air down (or up, depending on fan direction) the central plenum between tracks, through open spaces in the fan deck floor. In this way air travels through only one track of lumber before being reheated (Figure 23).

### Cross-Shaft Fan System

In the cross-shaft arrangement, fans are mounted on individual shafts aligned across the width of a kiln (Figure 24). The fans are usually mounted over a false ceiling and driven by individual motors of about 7.5 horsepower rating, either by a pulley system or, more commonly, by direct coupling. Motors may be mounted inside or outside the kiln. However, motors mounted inside a kiln must be of special construction to withstand high temperatures. Even so maintenance costs are high with such motors. Externally mounted motors must be protected from water vapor condensation in freezing weather.

Either multiple-blade disc fans turning at relatively slow speeds, or high-speed propeller-type fans may be used. The propeller-type fans deliver high volumes of air at high velocities through the load. They are particularly suitable for high-temperature drying of wood with a high initial moisture content and that has a high diffusion rate.

In double-track kilns movement of air through only one track before being reheated can be accomplished by using two sets of fans, one set aligned over each track. Air is then directed either down the center of the kiln where half goes through each track and returns to the fan deck and heaters, or half down each outer plenum, through one track width, and returns up to the fan deck and heat exchangers (Figure 25).

## Baffles

To achieve rapid and uniform drying, the heated air must be directed in a uniform distribution between the courses of lumber in the load. To do this effectively all other flow paths must be blocked so that air flow over, under or around the load is prevented. The practical way to accomplish this is by use of baffles, shown schematically in Figure 26.

Flow under the load on kiln trucks may be prevented by constructing the floor of the kiln with a channel just wide enough to accommodate the rails and trucks, and high enough so that the lowest course of lumber just clears the level of the floor. Alternatively, baffles may be steel panels hinged to the kiln floor or wood or plywood panels that are leaned against the load after it is pushed in. It is important that the panels make contact with the edge of the kiln truck without obstructing any rows of lumber above this level.

Flow over the load is most effectively prevented by use of ceiling-hinged baffles arranged so that their free end rests on the top of the load. As the load shrinks during drying, the baffles must be free to move down to maintain contact with the load. It is important that all loads in the kiln are constructed to the same height so that gaps will not occur above low loads.

Flow around the ends of a load can be prevented by hinged baffles at the corners of the kiln which are extended out to contact the load, or by a folding curtain which can be pulled out to the necessary length.

## Kiln Ventilation

Excess kiln moisture is normally discharged by opening roof vents. In most kilns, this is done automatically by the recorder-controller when the kiln humidity exceeds the programmed value. Automatic venting provides for better control and economy of humidification that can be achieved by manual or fixed venting because automatic venting is done only when the humidity is too high.

Ventilators are placed in the roof (Figure 27) on the intake and exhaust sides of the fan so that when they are opened fresh air is drawn in on the suction side and moist air forced out on the compression side of the fan. When the direction of rotation of the fans is reversed the flow of air through the ventilators is also reversed. The size and number of ventilators required depends on the species being dried, wet woods require more ventilation than drier ones.

Vents are arranged in-line along the length of the kiln, hinged, and connected by means of a continuous metal rod so that each line can be opened or closed as a unit by air motors operated by the recorder-controller.

As an alternative to the numerous roof vents required in a standard kiln some kilns are designed with a pressurized venting system. In one such system two identical metal ducts are placed inside the kiln, running full length in the zone above the false ceiling. These ducts vent to the atmosphere through louvered openings, one duct serves for air intake as the other exhausts. Adjustable openings along the length of each duct provide uniformity of air distribution throughout the kiln. A fan unit at the end of each duct acts interchangeably as intake or exhaust, depending on the direction of air circulation. When the fans are reversed, the venting system also reverses, with the louvers actuated to open immediately prior to the fans starting.

When venting is used to remove excessively moist air from a kiln considerable amounts of heat energy are lost with the expelled air. At the same time the cold make-up air consumes

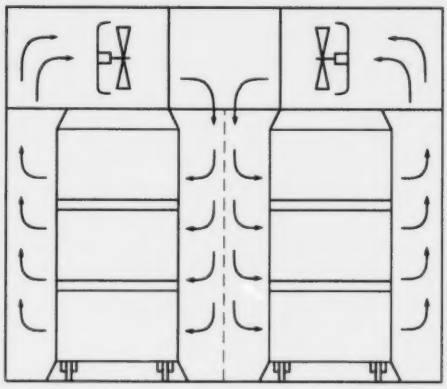

Fig 25 Single-air pass configuration of a cross-shaft, double-track kiln

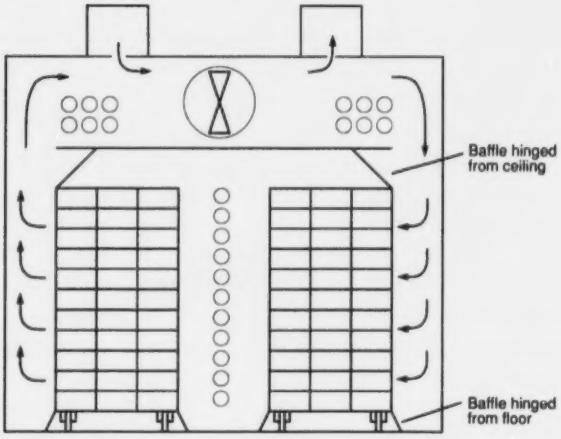


Fig 26 Baffles to direct air through lumber load

considerable energy in being heated to kiln temperature. Heat recovery units are now available that increase kiln efficiency by recovering energy from the vented air and using it to preheat the incoming air.

## Heating Media

Since the heat of evaporation of water is approximately 1000 Btu per pound, great quantities of heat energy must be generated and transferred to the circulating air and to the wood in the drying of lumber. Roughly speaking, the average amount of heat required in a commercial softwood kiln is about 1.5 million Btu per 1000 board feet. The principal methods of conducting this heat into the kiln are:

1. indirect, where a hot fluid is conducted into the kiln atmosphere through a suitable radiator; and

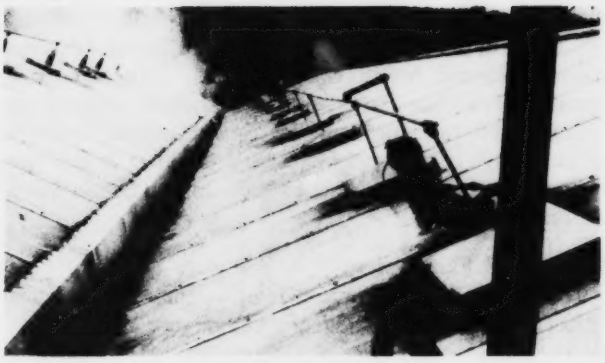

Fig 27 Roof-mounted vents

2. direct, where hot gases are discharged directly into the kiln atmosphere.

Examples of indirect heating systems are steam, hot water and thermal oil. Direct heating uses the combustion products of natural gas or other hydrocarbons discharged into the kiln after dilution to safe temperatures.

### Steam

The use of steam as a heating medium has certain advantages over other systems. Since heat is radiated into the kiln rather than being carried in by hot gases there is no displacement or change of kiln atmosphere when heat is added. Consequently, temperature can be controlled without affecting kiln humidity. Furthermore, where steam is available as a heating medium, it is also available to add water vapor so that relative humidity can be controlled at any desired value, even at the end of the drying cycle when kilns without a steam supply are unable to do so.

On the other hand, the capital costs of boilers and heating equipment are high. Boilers operated at more than 15 pounds per square inch gauge ("psig") pressure are required by law to be supervised by a staff of qualified engineers. Because of this, steam is not usually an economical source of heat even using waste wood as fuel, unless more than two large kilns are operated at one place.

Plain iron pipes were for many years the standard material for radiators. Fin piping is now almost universally used. Depending on diameter and other factors, it is considered that fin pipes have from four to eight times the radiating capacity of conventional black iron pipes. Fin pipes may be plain iron or copper tubing, on which thin metal strips are wound or discs are affixed in order to increase the radiating surface. Fins may be of various materials, heavy gauge steel being the most rigid and serviceable, but subject to corrosion, and aluminum being an excellent heat conductor but much more

subject to damage. The heat transfer rate of aluminum fins is stated to be twice as great as that of steel fins.

It is considered good practice to divide the heating coils into short, separately valved units serving short sections of a kiln. Short units produce more uniform temperatures along their length than do long coils. The return-bend system is the most common arrangement of steam pipes within a kiln. In this system, the pipes in each unit (kiln section), after leaving the distributing header, extend the length of the unit and return to a discharge header.

In double-track kilns where the circulating air passes through more than one load in a series, it is customary to install booster coils between the tracks to maintain a more uniform temperature within the kiln.

Almost the entire heat given up by the steam to the kiln is latent heat of evaporation. This means that for every 1000 Btu of heat delivered approximately one pound of water condenses in the steam lines. If it were allowed to remain in the coils it would prevent the entry of more steam and heating would quickly stop. In order to remove condensate, steam lines and radiators are built on a slope to permit drainage to the outlet end of the line. Here, **steam traps** remove the condensate and send it back to the boiler by means of a pump, or dump it into waste lines.

The effective working of a steam trap will result in fast heat up of the heat transfer equipment, maximum kiln capacity, maximum fuel economy and minimum maintenance. Steam traps can operate properly only if they are at the low point of the system. Installation of a trap at a higher elevation will result in the accumulation of condensate in the lower part of the steam line and will eliminate that part of the line as an efficient heat radiator.

Where a number of heating units are connected to the same trap the capacity of that trap must be adequate to handle the maximum condensing rate, otherwise flooding of some units may reduce their heating surface and unbalance the heating capacity of the coils.

### Hot Water

An alternative to the use of steam is an enclosed system using hot water under pressure as the heat exchange medium. The water is usually heated in a return-tube boiler to a temperature not exceeding 250°F using waste wood as fuel. This particular temperature is the boiling point of water at 15 pounds per square inch gauge pressure, the maximum steam pressure permitted without the supervision of a steam engineer. Customarily, the system is maintained under a hydraulic pressure of 15 to 160 pounds per square inch gauge to prevent steam from forming.

The hot water is circulated by means of pumps through radiators similar to those used in a conventional steam kiln. The lower amount of heat available from hot water (where no latent heat is present) in comparison with steam requires a greater radiating surface. Maximum temperatures attainable in the kiln are about 180°F (88°C), which is adequate for many operations, in particular those drying hardwoods.

### Thermal Oil

In recent years many systems have been installed that use mill waste, mainly planer shavings, to fire thermal oil heaters and circulate hot oil at low pressure through coils in the kilns for heat transfer to the circulating air. Advantages include the ability to achieve high kiln temperatures without the engineer requirements that accompany the use of high pressure steam.

### Gaseous Fuels

Because of the capital and high labour costs of steam and the low operating temperatures of hot water systems, many small and medium sized mills have installed hot air kilns. Almost all of these kilns use natural gas although a few use propane or butane as fuel.

Typically the furnace is located in the kiln control room at one end or at the side of the kiln. Air is withdrawn from the kiln, passed around the jacket of the burner, and is mixed with combustion gases in such proportion that the mixture has a temperature of 350 to 400°F. The discharge air passes into a plenum or duct running the full length of the kiln above the fan deck. Air in the plenum is vented into the kiln through holes along the duct. These openings should be adjusted to ensure uniform temperature along the length of the kiln. In some designs part of the hot air is conducted downward into a series of vertical columns each having two full-length exhaust slots on opposite sides through which the hot air is discharged uniformly throughout the kiln.

### Wood Waste

Wood waste has been used as a fuel for direct heated kilns. The apparent advantage of low cost fuel in this application is however, largely offset because complete, smokeless, particulate-free combustion requires an elaborate combustion unit. Wood waste continues to be favored however for indirect-heated kilns, particularly those using thermal oil as the heating medium.

## Humidification

In a gas-fired kiln with complete combustion and no excess air, the wet bulb temperature will approach 130°F at the end of drying. Where final conditioning is necessary to relieve case-hardening, steam must be injected.

Even where it is available, high-pressure steam should not be used directly to humidify the kiln. Steam at 100 pounds per square inch gauge has a temperature of 338°F; at this temperature, while adding to the kilns absolute humidity, steam will increase the kiln temperature so much that it will actually cause a reduction in **relative humidity**. Humidification should be done with steam at as low a temperature as possible;

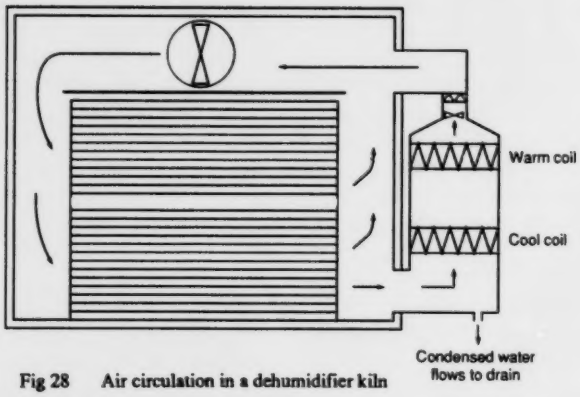


Fig 28 Air circulation in a dehumidifier kiln

that is, at 15 pounds per square inch gauge pressure. Where high-pressure steam must be used, it should be mixed with a water spray controlled by a thermostat to desuperheat the steam.

Installations of hot or cold water sprays were quite common in the industry. However, in many kilns so equipped the equipment is never used because of its ineffectiveness in changing kiln humidity. This is because evaporation of hot water at 212°F requires 970 Btu of heat per pound. The heat of evaporation must be taken from the air in the kiln. It can be shown that about 1200 cubic feet (34 cubic meters) of air must be intimately contacted and cooled 40°F (22°C) in order to evaporate one pound (0.45 kilograms) of water. This intimate contact and cooling is not possible in practice. Most of the water sprayed into the kiln does not evaporate but falls to the floor and drains away. As a result, there will be little increase in kiln humidity by the use of hot water sprays. Where cold water is sprayed, even more heat is necessary and the kiln atmosphere will be cooled, even though little water is evaporated.

## Dehumidifier Kilns

Dehumidifier kilns differ from "conventional" kilns almost only in the way that excess moisture is removed from the kiln air. In other respects including how the lumber should be loaded in the kiln, how air is circulated in the kiln and how moisture moves through and from the wood, both kiln types are identical. In conventional kilns excess moisture in the kiln atmosphere is removed by the process of venting which as noted earlier is a cause of heat loss also. In dehumidifier kilns a portion of the kiln atmosphere is drawn from the kiln and passed over the cool evaporator coils in a heat pump (Figure 28). The incoming air is cooled below dew point, some of the moisture in the air condenses, and the water is drained from the system. The cooler, drier air then passes over the warm coils of the heat pump condenser where it is reheated and returned to the kiln at a slightly higher temperature but a much lower humidity than the air left in the kiln. The drier air in the kiln can then absorb more moisture evaporated from the lumber.

These kilns are very energy efficient since:

1. no moist air is vented to the outside thus the energy contained in the warm, moist air is not lost; and
2. when the moisture in the air condenses on the cold coils of the dehumidifier, the heat of vaporization is recovered.

This advantage may be partially offset since dehumidifiers require electrical energy which is usually more expensive than other sources.

Controls for dehumidifier kilns vary with different manufacturers but among those available are:

1. control of dry bulb temperature and wet bulb depression;
2. control of humidity only via a humidistat; and
3. control of the percentage of time the compressor operates.

Typically the kilns have electric resistance heaters which are used to bring the kiln up to initial operating temperature and as back-up if the compressor cannot supply enough energy to maintain the desired drying conditions.

Current models of dehumidifiers are limited to an upper operating temperature of 160°F. They are widely used for drying the upper grades of softwood lumber being produced for specialty stock or for remanufacture. Very limited use has been made of dehumidifiers for drying the lower construction grades since advantage is taken of drying these in faster times at higher temperatures in conventional kilns.

The same patterns of stresses develop in wood dried by dehumidifiers as by conventional kilns, thus should it be necessary to relieve casehardening after drying, a supply of low pressure steam is required to raise kiln air humidity.

# CHAPTER 7

# Schedule Recording and Control

## Recorder-Controller

Until recent years an essential feature of a modern dry kiln has been the temperature recorder-controller which measures and records the dry and wet bulb temperatures within the kiln and controls them so that they coincide with those preset by the operator. A major development in kiln-drying technology that began in the mid-1980s was the introduction of computerized kiln controllers. These systems, most of which were developed in British Columbia, use a variety of proprietary programs that attempt to sense the rate or progress of drying and change kiln conditions accordingly. Operator input regarding selection of dry and wet bulb temperatures is minimal.

The conventional recording thermometers or psychrometer (Figure 29) plot on one chart both dry bulb and wet bulb temperatures. Recording thermometers may be actuated by mercury, gas or vapor. In all these, the pressure developed by expansion or evaporation of the fluid contained in the sensor in the kiln moves an expandable device in the recorder-controller housing; this, in turn, operates a recording pen and actuates pneumatic devices that control the operation of heaters, steam valves and vents to maintain the desired conditions within the kiln.

Vapor-actuated thermometers are the most widely used in Canada. They can be recognized by the fact that temperature graduations on the chart increase in size at higher temperatures. These instruments can supply accurate information on kiln conditions and perform accurate control only if they are properly calibrated and in good operating condition. The operation and maintenance of this type of recorder-controller is described in detail by McIntyre (1983).

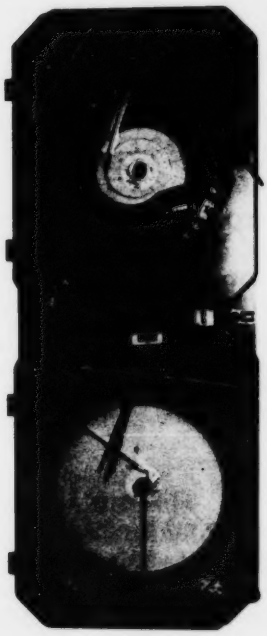

Fig 29 Cam controller with recording chart

## Time-Based Control

Until the introduction of fully automatic computer controls almost all western kilns were equipped for control of time-based schedules (see Chapter 10). In its simplest form dry and wet bulb settings are made by the operator according to the prescribed schedule for a given species and size. The process can be automated on some controllers by using two cams (Figure 30), one to control the dry bulb temperature and the other to control the wet bulb temperature. A further advantage of using a cam system is that changes in temperatures can be made to occur gradually rather than when a change is made manually in a single step. Sudden changes in kiln conditions

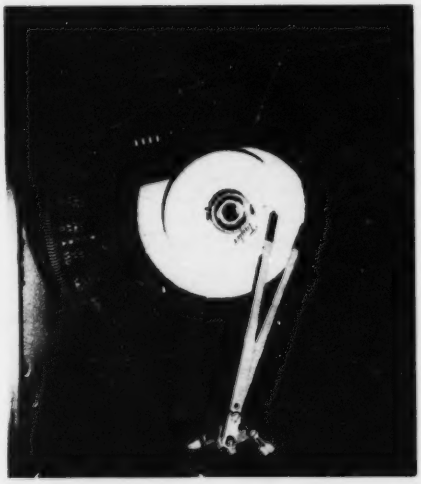

Fig 30 Cams for control of kiln temperatures

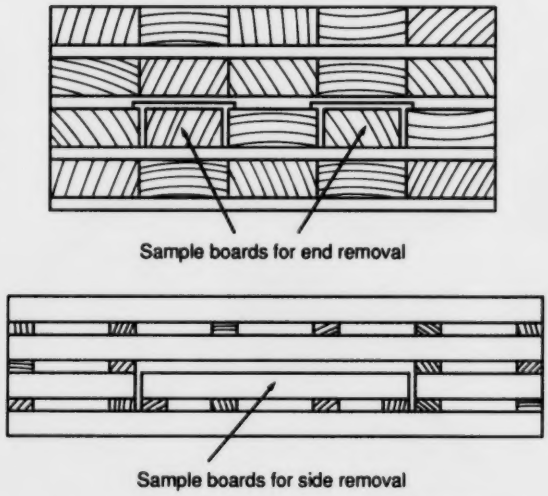


Fig 31 Location of sample boards to be weighed periodically during drying

can initiate surface checks in some woods when surface moisture content drops rapidly.

## Moisture Content-Based Control

Changes in a step-wise drying schedule are best made when the lumber in the kiln reaches given moisture contents. There are however limited ways of measuring moisture content while wood is drying and at best only average values can be obtained. Methods include use of lumber weight as an indicator of moisture content, and indirect electronic indicators.

## Lumber-Weight Method

Laboratory test kilns are frequently designed so that an entire load rests on a weighing system so that weight loss can be measured continuously throughout a run. If a reasonable accurate measure of the initial average moisture content is made, moisture content can therefore be calculated. No commercial use of this process is presently known to exist.

An approximation of this method using selected sample boards from a load is used widely, particularly for products requiring long drying times. It could also be applied in drying high-grade softwoods where long schedules are used, hence it is described here. The method consists of placing a number of prepared sample boards in a load to be dried so that they can be withdrawn at intervals, and weighed to estimate their moisture content.

Boards from which samples are to be cut should be selected while the lumber is being piled for drying. The samples (Figure 31) should be taken from those boards most representative of the driest and wettest, thickest and thinnest, edge-sawn and flat-sawn, and from boards containing varying amounts of sapwood and heartwood. The end 2 feet of these boards are trimmed off and the first 1-inch long moisture-content section is cut. Next, a 4 to 5-feet long sample board is taken, followed immediately by the second moisture-content section. Neither the moisture-content sections nor the sample boards should contain pitch pockets, rot, knots, or bark.

Sample boards should be end coated with paint or other substance to prevent end drying. They are then built into the stacks in such a way that they can be removed easily, either from the side of a stack or from the end of a stack. When sample boards are to be removed from the side of a stack, the kiln stickers immediately above them are sawn shorter by a distance equal to the width of the sample board. This means that no weight bears on the samples and they can be withdrawn easily, weighed and replaced in the stack. To remove samples from the end of a stack is more difficult. One method is to use special stickers above the rows containing the sample boards. These stickers are notched out to half their full thickness at the position of the sample boards, so that again no weight bears down on the sample boards and they can be pulled out easily (Figure 31).

Each time the sample boards are removed they are weighed and their moisture contents are calculated as described below:

First calculate average moisture content of each sample board using the procedure described in Chapter 3. For each calculate oven-dry weight according to the formula:

$$\text{Oven-dry weight} = \left(\frac{\text{Original (green) weight}}{\text{Moisture content} + 100}\right) \times 100$$

Each time a sample board is removed during drying its moisture content is calculated according to the formula

$$MC = \left(\frac{\text{Weight at time of removal - Oven-dry weight}}{\text{Oven-dry weight}}\right) \times 100\%$$

Changes can then be made in schedules when either the average of the moisture contents of all the sample boards reaches a change point, or when the wettest sample board reaches a change point.

It will be obvious that the sample-board method would be difficult to use where automatic stackers are used. In addition, since access to the kiln is necessary, it can only be used when the kiln temperatures are low enough to permit entry, and the method cannot ever be used in direct-fired kilns where the kiln atmosphere is poisonous.

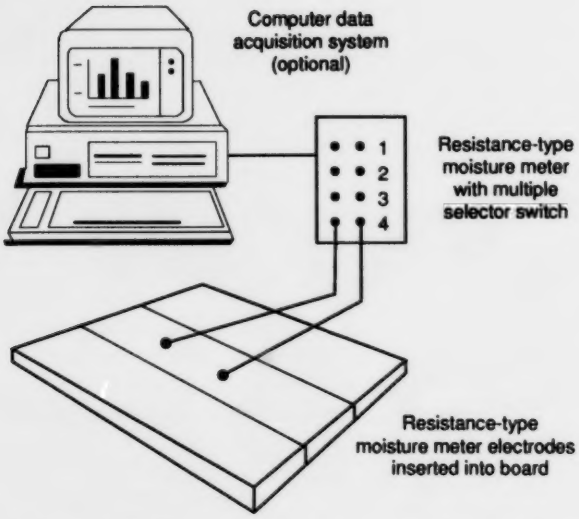


Fig 32 Measurement of board moisture content during drying using resistance-type moisture meter electrodes

## Electronic Methods

Methods available for estimating moisture content during drying for kiln control include implanted electrodes in boards to measure electrical resistance, and surface contact electrodes to measure electrical capacitive admittance.

In the **resistance method**, lumber moisture content is determined using sets of electrodes inserted into predrilled holes at one or more depths in each of a number of boards in the kiln charge (Figure 32). The principle of measurement is almost identical to that of hand-held moisture meters described earlier in Chapter 3. Kiln control of drying rate is accomplished by adjusting kiln temperatures to maintain a predetermined ratio between moisture contents measured in the sample boards and the equilibrium moisture content of the kiln air. The latter is measured also by electrical resistance measured across electrodes clamped to a small wood sample or wood wafer in the kiln. Limitations of this type of control include the inaccuracy of resistance-type systems above fiber saturation point, and a time-based schedule may have to be used until this is reached. Additionally, the selection of the sample boards to adequately represent the entire load, and their location in the load, clearly influence the accuracy of the system.

European and U.S. manufacturers of this type of control system typically use microprocessors or computers to store a selection of time- or moisture content-based schedules. The computer will also continuously calculate new settings for equilibrium moisture contents and drying temperatures depending on average moisture content or time, and collect and store data on drying conditions, energy consumption, etc. to prepare management reports for each drying run.

In the **capacitive admittance** system, shown diagrammatically in Figure 33, the sensing elements consist of thin metal strips which are placed into a sticker opening at a given height above ground. Up to nine can be located along the length of a kiln track. A flexible cable from the control cabinet is then attached to each of the sensors. An electrical signal is sent to the sensor and the circuit is completed from the sensor to the kiln floor or rail.

When operated as an in-kiln moisture meter, the control cabinet displays a moisture content value for each of the sensor locations or an average of all in use. Readings above 30 percent moisture content are generally off-scale, and so the meter can provide guidance of drying progress only in the later stages of drying. Calibration of the values displayed must be carried out for each species used.

Some characteristics of these meters are: readings are influenced largely by the row of lumber that the sensor rests on; surface moisture content of the wood in that row has a major impact on meter readings; and the wettest pieces in contact with the sensor have a predominant effect on readings. The system can also be integrated into a kiln control package although it may be necessary to operate with a time-based schedule until readings reach about 30 percent. A useful feature is that kilns are shut down when a predetermined average value is reached.

## Computer Controls

The largest change in kiln technology in recent years has been the development and implementation of computer-based kiln control systems. Many users credit this new technology with significant savings in kiln-drying times, energy consumption and overall drying costs. Many of the benefits have their origin in improved control of final moisture content, so that overdrying and resulting degrade are minimized.

Unlike the European and U.S. systems described earlier, the computer control systems developed in British Columbia differ by not measuring moisture content directly, for example by using resistance probes inserted into selected boards. Rather, the British Columbia systems infer or calculate moisture content by interpreting a range of kiln conditions including temperature drop across the load, energy responses and venting frequencies.

Temperature drop across the load ("TDAL") is a parameter used by several manufacturers and is a measure of the amount of energy given up by air in evaporating moisture as it passes over wet wood surfaces. Typically most woods will produce a large temperature drop across the load at the start of drying with this value becoming smaller as drying progresses. With experience a given temperature drop across the load value can be interpreted as an end point in drying and an indicator of when to shut down a kiln.

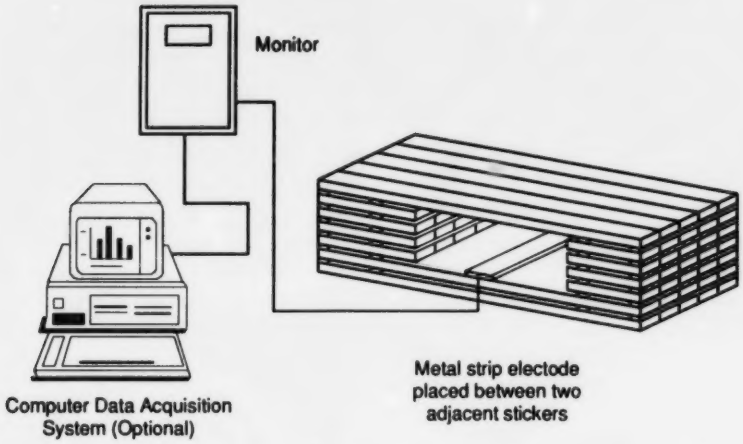


Fig 33 Capacitive admittance in-kiln moisture meter

The response of the lumber in a kiln to a particular input of energy can be used to trigger kiln schedule changes and shut down. For example the ability of a kiln to maintain a desired dry bulb temperature upon reduced output from a combustor can be interpreted in terms of moisture content since more energy will be transferred to a wetter load than to a dryer load.

The amount and frequency of venting can similarly be interpreted in terms of progress of drying since in most drying programs the drying rate, or evaporation of water, slows down considerably as the end-point is approached.

Each of the computer control systems available uses signals such as the above as part of their own proprietary drying models and control algorithms. Input from a kiln operator may be limited to entering via a keyboard the species and sizes to be dried and required final moisture content, and the computer will select a drying program to be followed. The complexity of the model employed in part dictates whether one computer controls only one kiln or several.

The technology can be expected to continue to evolve, therefore details are provided in general terms only.

## Reference

McIntyre, S. 1983. Operation and Maintenance of Pneumatic Recorder-Controllers for Dry Kilns. Forintek Canada Corp. Special Publication SP9R. 23p.

# CHAPTER 8

# Kiln Performance and Testing

Proper drying of lumber requires that the kiln building and all of its equipment be in good working order at all times. To accomplish this it is necessary that all aspects of the kiln be inspected regularly and that repairs be carried out as soon as faults are found. Modern aluminum kilns with a sound internal vapor barrier are clearly going to encounter less problems than old masonry block kilns that over the years will likely have developed cracks and leaks. An ongoing maintenance program appropriate to kiln age and type of construction, temperatures being used, and species being dried should be developed between a mill and kiln supplier.

Detailed maintenance procedures are beyond the scope of this handbook, however some procedures for evaluating the performance of a kiln are suggested. These procedures are those that are systematically followed by Forintek technologists as part of an on-site industrial kiln testing program.

Kiln structure and components are examined. Defects noted can include cracks and leaks in kiln walls and roof; misfitting kiln doors or deficient gaskets; missing or damaged baffles; poorly located dry and wet bulb sensors; gaps in fan walls; wrong fans on line-shafts; and improperly opening or closing vents.

Three elements of kiln performance that are essential to good drying are uniformity of air velocities through the stickered packages; uniformity of air temperatures along the length of the kiln; and accurate calibration of the controlling-recording apparatus.

Fig 34 Air flow measuring devices

## Air Velocity Distribution

A typical green load should be placed in the kiln, all usual baffles set in place, and the fans activated. Regular intervals are selected along the length of the kiln, for example, every 10 feet or, in track-loaded kilns, about one-third and two-thirds along the length of each cart. At each location air flow is measured below the cart, one-quarter, one-half and three-quarters up the edge of each package, in the bunk spaces between packages and above the uppermost package. Air flow is always measured on the leaving-air side of a kiln or track. The procedure should then be repeated with fans reversed.

Measuring instruments for air flow are of three main types, anemometers, velometers and flowmeters. In a hot-wire anemometer (Figure 34a) the wire in the probe is heated by electricity from a battery in the unit. When placed in an air stream the heated wire is cooled in proportion to the velocity of air flow. Velocities are indicated directly on a scale calibrated in feet per minute. These instruments are very accurate but expensive, and care must be taken to prevent damage to the heated wire.

In the velometer type (Figure 34b) the air stream enters the instrument through an opening or jet causing a slight difference in static pressure which is proportional to the air velocity. Velocities are indicated directly on a scale calibrated in feet per minute. The instrument is calibrated for air at a certain temperature, humidity and pressure and for maximum accuracy corrections are applied when used under different air conditions.

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 190 | 360 | 150 | 190 | 250 | 380 | 120 | 100 | 150 | 190 | 150 | 120 | |
| 100 | 300 | 210 | 90 | 100 | 110 | 120 | 60 | 200 | 150 | 320 | 150 | 900 |
| 120 | 360 | 180 | 160 | 100 | 110 | 140 | 60 | 170 | 90 | 50 | 150 | 800 |
| 160 | 210 | 100 | 300 | 200 | 100 | 220 | 100 | 240 | 80 | 175 | 250 | 600 |
| 330 | 500 | 280 | 280 | 530 | 1000 | 400 | 375 | 560 | 280 | 275 | 250 | |
| 270 | 230 | 450 | 220 | 320 | 110 | 650 | 700 | 190 | 280 | 300 | 200 | 700 |
| 500 | 110 | 130 | 600 | 750 | 150 | 210 | 180 | 150 | 300 | 200 | 150 | 600 |
| 430 | 720 | 250 | 110 | 350 | 850 | 70 | 190 | 155 | 750 | 140 | 340 | 500 |

Car No. 1 2 3 4 5 6

Fig 35 Air velocity locations and measurements (ft./min.) on east side kiln #6

A very simple and inexpensive air speed indicator is shown in Figure 34c. In this flowmeter type of instrument, air is directed past a small ball in the central tube and the height up the tube that the ball rises is proportional to air flow which is read directly in feet per minute.

Air flow data should be tabulated in a form such as shown in Figure 35. It is immediately obvious where corrective actions are needed. These may include excessive air loss above, around or below packages showing that baffle repair or replacement is needed, or areas of abnormally low flow suggesting that a fan may not be functioning. Other problems associated with improper piling or loading (Chapter 9) are also found in this test.

Table 4. Moisture Content Distribution in SPF Dried in a Kiln with Significant Temperature Variation End-to-End

| Moisture Content (%) | Package A (cool end) | Package B (warm end) |
|---|---|---|
| | Number of Pieces | |
| ≤ 7 | 0 | 1 |
| 8 | 0 | 1 |
| 9 | 0 | 16 |
| 10 | 0 | 52 |
| 11 | 0 | 48 |
| 12 | 0 | 30 |
| 13 | 0 | 15 |
| 14 | 0 | 5 |
| 15 | 0 | 5 |
| 16 | 2 | 2 |
| 17 | 10 | 1 |
| 18 | 6 | 1 |
| 19 | 19 | 1 |
| 20 | 32 | 0 |
| 21 | 28 | 1 |
| ≥22 | 25 | 1 |
| Average MC | 20.1% | 11.3% |

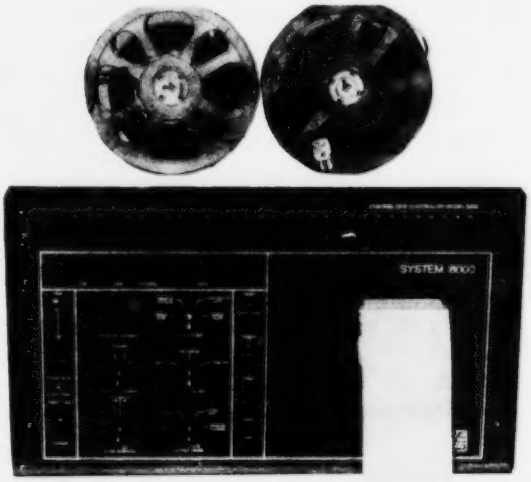

Fig 36 Printer-recorder with thermocouples

## Temperature Distribution

After air velocity tests are completed and before the drying program or schedule is begun, temperature sensors are placed in the kiln. The simplest and easiest sensors to use are thermocouples. About 30 are placed in the kiln at 8 or 10 feet spacings along the outside of each track, and at the location of each dry and wet bulb in the kiln. The thermocouple wires are fed back to a printer-recorder (Figure 36) which is located in a protected environment, usually the kiln control room. The kiln is then started and drying proceeds either under direct control of the operator applying a regular time- or moisture content-based schedule, or under control of a computer-based system.

The thermocouples measure temperature throughout the run and these values are printed out at regular intervals, for example every two or four hours depending on length of schedule. This provides a means of identifying areas within a kiln that are operating at, above or below required temperature levels.

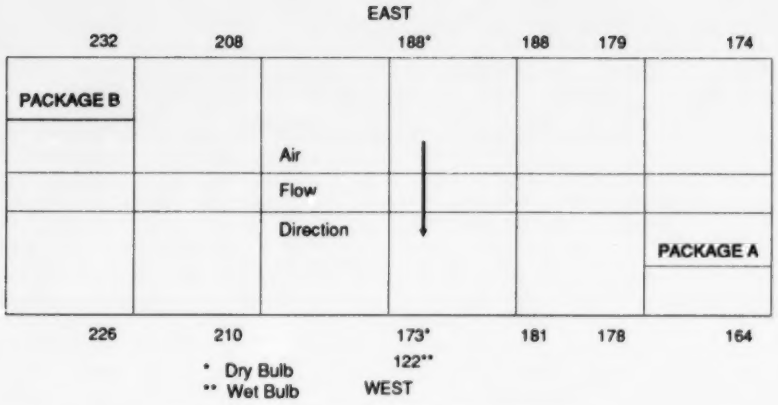


Fig 37 Thermocouple temperature at 30 hours

Based on both the previously measured air flow distributions in the kiln and the temperatures now noted, it is possible to identify areas in the kiln where unduly fast or slow drying can be expected. Upon completion of the drying run, packages of lumber from these areas are selected for piece-by-piece measurement of moisture content and degrade to demonstrate the effect of non-uniform air flow and temperature on drying. Figure 37 is a schematic example of a double-track, hot-air kiln with considerable variation in dry bulb temperature end-to-end. Table 4 demonstrates the very great differences in moisture contents in package A from the cooler end of the kiln compared to package B from the warm end.

## Recorder-Controller

The calibration of a recorder-controller should be checked at regular intervals, at least every six months. Bulbs or other sensing elements should be taken out of wall-mounted brackets and immersed in water or oil heated to a range of temperatures equal to that within which the kiln operates. The recorder pen should track the temperature accurately to within 3°F, and other functions including opening and closing of roof vents, steam spray valves and heating valves should similarly correspond. As indicated earlier, maintenance procedures for pneumatic recorder-controllers have been described by McIntyre (1983). Unless an operator has had some instruction or experience in calibrating instruments of this type and has the equipment for making adjustments, calibrating and adjusting should be left to a qualified instrument technician who will guarantee instrument function within its limits of accuracy, usually plus or minus 1°F.

## Reference

McIntyre, S. 1983. Operation and Maintenance of Pneumatic Recorder-Controllers for Dry Kilns. Forintek Canada Corp. Special Publication SP9R. 23p.

# CHAPTER 9

# Preparing Lumber for Drying

The proper preparation of loads or packages of lumber and their assembly on kiln carts and in the kiln is essential for uniform drying. Any lack of conformance to the procedures described below will be at the expense of causing more drying degrade, widening the range of final moisture contents and extending kiln-drying times thereby causing excessive energy consumption and reduced kiln throughput.

## Segregation

The drying time of any piece of lumber is determined not only by the schedule used but also by lumber characteristics such as species, which determines density and permeability, moisture content, and size. Consequently, production can be increased and a more uniform product obtained by drying lumber of uniform characteristics. A charge of lumber should therefore consist of wood from a single species, or mixed species of similar drying characteristics, a single dimension, and a low range of initial moisture contents.

## Moisture Content

The ability to presort lumber before going into a kiln according to its "green" moisture content clearly provides one of the best means of optimizing kiln efficiency. This is because sorted wood all of a reasonably uniform moisture content will dry more evenly than lumber of mixed moisture contents. The greatest benefits will come about in reducing kiln times and energy consumption for lumber already of a low moisture content, and reduced degrade losses caused by overdrying of drier pieces in a mixed load. This concept has been recognized for many years but only recently has a method been commercialized to perform this function.

Forintek developed a system to sort by moisture content in the mid-1980s and commercial installations began in 1988. The principle is one of provocative infrared non-destructive testing. A known amount of heat is radiated onto the surface of a piece of lumber. After a fraction of a second while the moisture in the wood absorbs the radiation, the system senses the temperature of the wood at the spot the radiation hit and compares this temperature to that of unheated regions. The higher the moisture content of the wood, the lower will be its temperature and the smaller will be the temperature difference between a heated region and an unheated reference region. A microprocessor manipulates the temperature difference data to provide moisture content readings.

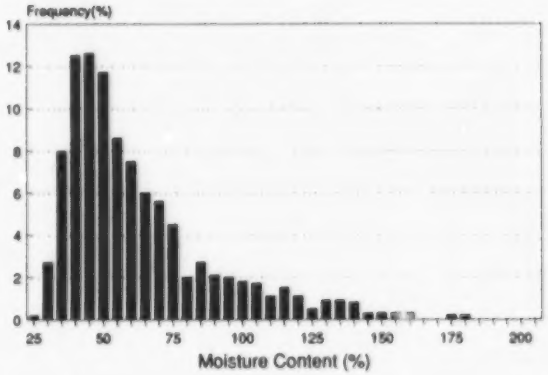


Fig 38 Moisture content distribution in green hem-fir lumber

A mill using this technology selects a moisture content level at which the sort is to be made, for example less that 35 percent and more than 35 percent moisture content, and lumber is directed to appropriate bins accordingly. Typical applications are for sorting wet alpine fir from a mix of spruce-pine-fir; sorting already dry spruce and pine where beetle- or fire-killed timber has been harvested; and sorting very wet hemlock from a typical hem-fir mix. Figure 38 portrays a typical moisture content distribution found in a charge of green hem-fir.

## Length

The mixing of several lengths in the same load or package results in overhanging ends (Figure 39) leaving large gaps between loads. Because air passing through these gaps bypasses the greater part of a load, overall circulation is reduced and drying time increased. On the other hand while the greater part of the load is exposed to reduced circulation, the overhanging ends are exposed to an abnormally high volume of air, and dry considerably faster than the bulk of the charge. This results in both nonuniform drying and end-checking of lumber. In addition, because of lack of support and restraint, the ends are subject to warping and breakage. If mixed lengths must be used, not more than two lengths (for example 10 and 12 feet, or 14 and 16 feet) should be piled together. If this cannot be accomplished, box-piling is recommended. In this method (Figure 40) the longest pieces are placed at the side of

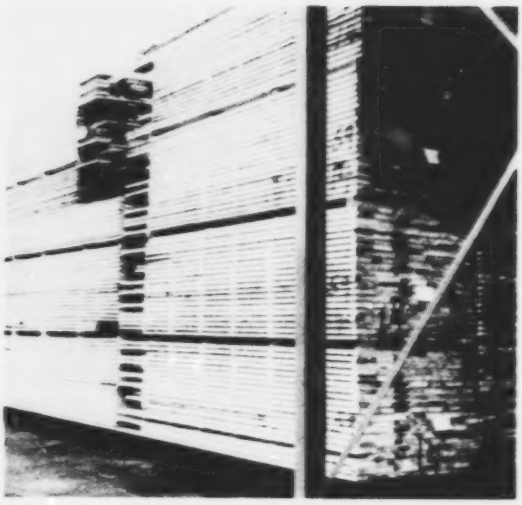

Fig 39 Mixed lengths in a kiln charge

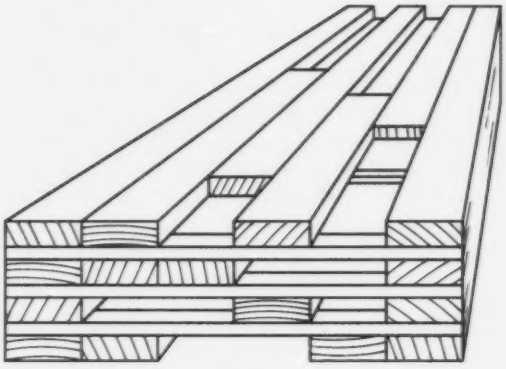

Fig 40 Box-piled package with longest lengths placed at sides

a pile in order to restrict the amount of air bypassing a load. Shorter pieces are placed on the inside, placed alternately flush with either end. There should be no overhanging boards.

## Width

Widths should be uniform throughout a kiln charge, or at least not vary more than 4- with 6-inch wide, or 8- with 10- and 12-inch wide. This avoids the mixing of narrow width, high moisture content sapwood with wider, predominantly heartwood pieces which have significantly lower moisture content.

## Thickness

Thicknesses should never be mixed (for example 1 x 6 with 2 x 6) in a kiln charge since clearly both overdrying of the thin and underdrying of the thick stock can occur. The practice of "doubling" 1 inch stock with stickers only every second row, to simulate 2 inch stock is not recommended since when the kiln packages are broken down the boards will be wetter on the faces placed together and may cup upon further drying.

## Piling Lumber For Kiln-Drying

Piling or stacking lumber involves assembling boards in horizontal rows or tiers, each row separated by a number of regularly spaced strips or stickers. The spaces formed by the stickers are the passageways for the circulation of air. Lumber may be piled directly onto kiln carts which are pushed or pulled on rails into a kiln. This type of stacking which can be done manually or automatically, eliminates the need for bunks at intervals up the height of the load. All of the spaces are therefore sticker spaces and air circulation should be very uniform. Alternatively, lumber may be piled as packages which are assembled to the desired height with fork-lift trucks. The thick bunks separating packages can disrupt the uniformity of air flow.

Piling is one of the most important steps in the lumber drying process and it is important to note that all of the improvements in kiln designs and kiln schedules cannot offset drying degrade which originates by poor piling practices. The principles of piling are very simple.

Stickers are placed at regular intervals, one every 3 to 4 feet is common, on each row of boards so that the rows of stickers are in perfect vertical alignment. The stickers should also be in alignment with the thicker bunks below each package and those on the kiln cars. In this way, all of the downward thrust is in a perfect line and there can be no tendency for boards to be forced out of shape due to misplaced stickers. Figure 41 illustrates these points. The sides of the pile should be as even as possible, with no boards projecting beyond the others. Boards which do protrude will act as deflectors, causing more air to flow through some air slots and less air to flow through others.

The outermost stickers should be placed as near to the ends of the boards as possible. This minimizes warp at the board ends, which tend to dry faster, and it also reduces the tendency for end checking. Problems can arise when package loading is used since, when a long load is picked up by a fork-lift truck, the deflection of the lumber allows the end stickers to fall out. This can be overcome by fastening a temporary strap around the end of each package to hold the stickers in place while the lumber is being moved, or by placing additional stickers at 2 feet spaces in the lower six to eight rows.

Fig 41 Excellent sticker alignment

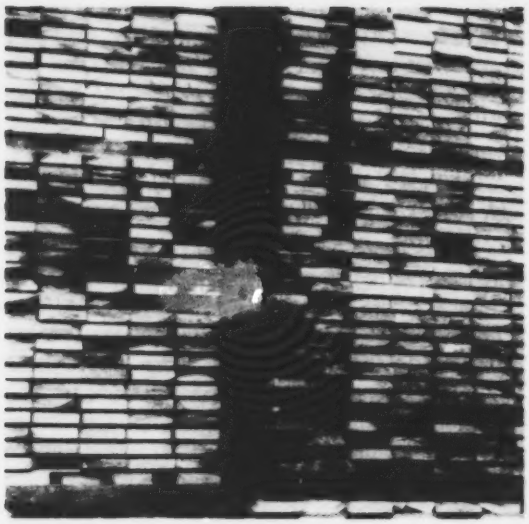

Fig 43 Chimney space between packages

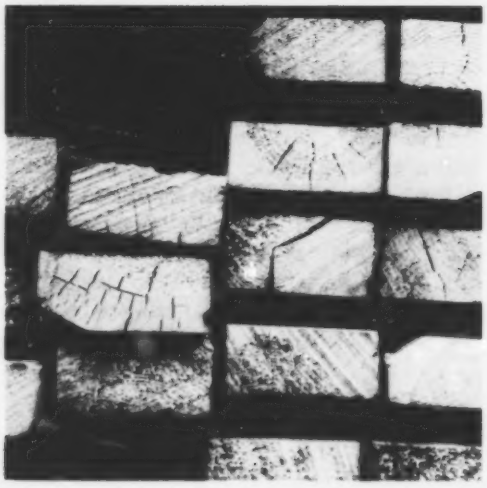

Fig 42 Air passageways blocked between packages

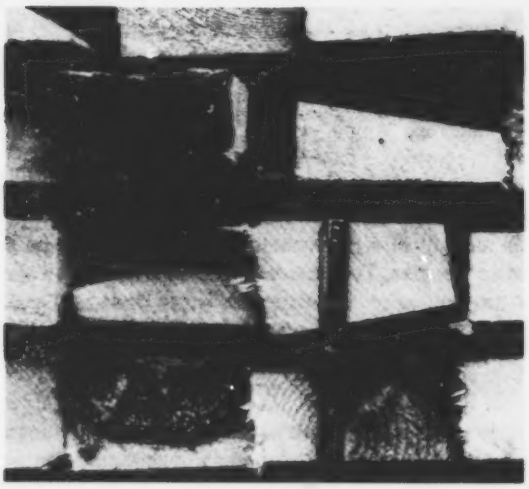

Fig 44 Lack of restraint of thin boards because of thick boards

In some loading systems, stickers do not span the whole width of the pile. For example, a 9-foot-wide pile in a package-loaded kiln may consist of two 4-1/2-foot-wide packages side-by-side. In these situations, some air slots in one package may not line up with those in the adjacent package (Figure 42). This causes a great resistance to air flow through both packages reducing the air velocity and slowing the drying rate. To overcome this problem, a space of 2 to 3 inches must always be left between the packages (Figure 43), so that the air can move easily from the exit side of the air slots of the first package to the entry side of the air slots of the second package.

## Sticker Size

Stickers are usually 1-1/2 to 3-1/2 inches wide. If narrower than this, stickers can bite into soft lumber and this reduces the size of the air slot. If wider, the wood under a sticker may

not dry and pockets of wet wood will be left along the lengths of boards.

Sticker thickness is a subject which attracts a lot of attention. Some claim that drying is faster with thin stickers, while others have found results to the contrary. The most common sticker thickness is 3/4 inch followed by 5/8 inch and 1/2 inch. By reducing sticker thickness more lumber can be placed in the kiln. For example, in a given lumber pile 15 feet high consisting of green lumber 1-3/4 inches thick and 3/4 inch thick stickers, the volume of lumber in the kiln could be increased 11 percent by reducing sticker thickness to 1/2 inch.

The result is that air velocity in feet per minute ("FPM") is increased, but air volume (cubic feet per minute ("CFM")) through each sticker space is reduced. This is not the same effect that would be obtained by increasing the speed of the fans where an increase in air volume would also be obtained. The thinner stickers create more air passages; therefore, the air being circulated by the fans is divided up between the greater number of passageways. Consequently, the volume of air flowing between any two rows of lumber is less. The reduced air volume flow causes a greater temperature drop across the width of the pile, less uniform drying conditions, and a greater spread of final moisture contents. To change to thinner stickers, without causing a wider spread of final moisture contents, would require an increase in the total drying time. The benefits gained by loading more lumber into the kiln may therefore, be offset by the extra time required to dry to the desired moisture content.

Some mills in the 1970s obtained reduced drying times with thinner stickers which were made from glued-laminated veneers or reinforced thermosetting phenolic laminates. These new stickers were very much stiffer and stronger than ordinary wooden stickers, with the result that they were more able to remain straight in a pile containing lumber of uneven thicknesses and lengths. The clearer air passages so formed allowed better air circulation and therefore better drying. Escalating costs of some of the petroleum-based components of these stickers however, caused them to lose market competitiveness with wood stickers despite their improved performance.

## Piling Warp-Prone Lumber

Some lumber is naturally warp-prone; for example, lumber sawn from juvenile wood near the pith is likely to twist, and lumber sawn from logs containing reaction wood can develop crook or twist. Piling such material demands extra care because, if the lumber can be held perfectly flat and straight during drying, then there is an excellent chance that it will remain straight when it is unpiled, planed and put into service.

Stickers must be in perfect alignment and there must be more of them, one for every 2 feet of lumber length. Sawing should be to very close thickness tolerances because a mixture of thick and thin pieces will result in the thinner pieces having no restraint from the stickers and they will be free to warp (Figure 44). Most losses from warp occur in lumber near the top of the lumber pile since that lumber has little or no weight above it to hold it flat. To save this lumber from degrade, weights in the form of concrete blocks or steel I-beams can be placed on top of the loads. A number of hydraulic, spring-loaded clamps have also been promoted for restraining against warp. To be effective they must be capable of maintaining pressure on the load as it shrinks in height due to thickness shrinkage of individual boards during drying.

Lumber sawn from larger, mature logs seldom gives warp problems during drying but the utilization of smaller, younger logs can be expected to make this an increasing problem in the future.

# CHAPTER 10

# Drying Schedules and Special Treatments

The information provided in this Chapter is applicable mainly for conventional kilns over which a kiln operator has control. That is, kilns that operate with pneumatic or electronic recorder-controllers with manual or cam-controlled automatic dry and wet bulb settings. It applies less for kilns which are controlled by a fully automated or preprogrammed computer controller as described in Chapter 7, since these systems respond to certain kiln or wood conditions that have been selected by the particular controller manufacturer.

Problems and limitations associated with electronic measuring of moisture contents over an entire drying cycle were described in Chapter 7. It is for these reasons that all of the schedules described below are time-based. Each schedule therefore consists of a set of dry and wet bulb temperatures to which the kiln air is conditioned during the drying from initial to final moisture content. The kiln conditions are changed at the time intervals shown. In general, the drying conditions are made progressively more "severe" as drying proceeds, by raising dry bulb and/or lowering wet bulb temperatures, to reflect that water becomes more difficult to extract as moisture content falls, but recognizing that drying defects must be minimized.

These schedules should be viewed as being appropriate for lumber with normal green moisture contents dried in modern, efficient kilns with all major controlling and operating equipment in good working order. Any one schedule may however, produce different results in different kilns. It is important to be aware of the factors that influence drying in addition to the temperature settings being used. Some of the more important of these are:

## Air Flow

Unless otherwise stated, the air velocity through a stickered load is assumed to be around 450 feet per minute. If flow rates are significantly lower or higher than this value, drying in the first third to half of a cycle will be slower or faster respectively. The length of the initial drying period should be correspondingly lengthened or shortened. Sticker thickness is usually 3/4 to 11/16 inch and velocities are quoted based on this size. Quality of piling and loading can affect air flow particularly if a chimney is not left between side-by-side packages on kiln cars.

## Heat Capacity

Kilns of the same size may differ in how fast they can reach the initial temperature setting. In steam kilns this may be due to differences in steam pressure and therefore temperature, or because of differences in steam coils and heat release capacity. In gas-fired hot-air kilns it can be due to different sizes of furnace and volume of heated air directed to the kiln. Particularly in short, high temperature drying cycles a fast or slow heat-up capability can vary total drying time by several hours which can represent a substantial percentage difference when comparing two kilns. The effect is much less noticeable in longer cycles where the initial temperature setting may be relatively low.

## Lumber Thickness

Lumber of the same nominal thickness but sawn to different target sizes, for example 1.8 compared to 1.7 inch will result in slightly longer drying time for the thicker material. Of more significance however, is the variation of lumber thickness within a single charge since it will be necessary to extend drying time of the entire charge to ensure that the thicker pieces reach the required final moisture content. In addition to extending drying time, this causes overdrying of thinner or on-size pieces resulting in greater likelihood of degrade.

## Lumber Moisture Content

The standard schedules generally assume that lumber is fresh sawn and has a green moisture content typical for the species. Any drying that occurs before the wood is placed in the kiln will require that kiln time be shortened, otherwise overdrying will occur. Examples of pre-kiln-drying would include air drying, either in an air-drying yard or in a kiln yard while waiting to be loaded in the kiln; drying that occurred in the logs if extensive storage had occurred; and drying that occurred in the trees if damaged or killed by fire, insect or disease. Technology that can be used to lessen the impact of widely varying or unknown green moisture contents include the lumber moisture sensor (Chapter 9) for sorting according to moisture content class, and the in-kiln moisture meter (Chapter 11) for identifying kiln shut-down point.

## Modifying Kiln Schedules

If drying times or lumber quality are not acceptable, it should not be immediately assumed that the kiln-drying schedule is at fault. The performance of the kiln, particularly the uniformity of heating and air flow, should be determined. Lumber quality can be improved by some specific changes to schedules:

### To Reduce Degrade

Surface checking is due to too rapid drying of surface layers relative to the core of the wood, so that the surface tries to shrink but is prevented from doing so by the still-swollen core. If the wet bulb depression is reduced in the early stages of drying, surface moisture content will be higher and the likelihood of checks reduced. Lumber that has surface checked during air drying should not be exposed to steaming or high relative humidity before or during kiln-drying, since the checks will frequently lengthen, widen and deepen.

Internal checking is usually related to severe casehardening. It occurs when excessive tension stresses are set up in the core as it tries to shrink but is prevented from doing so by the surface which is set in a stretched condition. The checking can be minimized by not applying high temperatures until all free water has been removed from the core. In practice, there is no way of monitoring this, therefore if internal checking develops in one drying run the schedule should be modified for the next by using lower temperatures in the last one-third to one-quarter of the schedule.

Checked knots can be reduced in severity by drying at a higher humidity in the initial stages of drying but can only be eliminated in many species by not drying below 15 to 18 percent moisture content.

Collapse, which is evident either as surface distortions or internal checking, is the result of cell walls buckling due to surface tension forces exerted on them as free water leaves cell lumens. As temperatures increase, the strength of wet cell walls decreases. Therefore, when drying collapse-prone material, usually only western red cedar from some wet areas, low temperatures (not exceeding 130°F) should be used until fiber saturation point is reached.

Warp, in its various forms, while a frequent problem in the kiln-drying of western softwoods, is generally not related to kiln schedules. It is often due more to poor piling and loading practices. Warp will be increased by overdrying below the target moisture content. This points to shortening a kiln schedule and is best accomplished by use of an in-kiln moisture meter as described earlier.

### To Improve Moisture Content Uniformity

It is normal that there should be a spread in the moisture contents of pieces of lumber in a charge at the end of kiln-drying. This arises from a number of factors including variations in initial moisture content, density, and grain angle of the wood, and unequal drying conditions throughout the kiln. Additionally, the faster the schedule that is used the greater will be the spread in final moisture contents. This effect is particularly noticeable in high-speed drying of spruce-pine-fir since each of the three species in the group dries at a different rate.

A substantial spread in moisture contents usually presents little problem in the utilization of structural lumber, but for lumber that is to be further manufactured only a very small range in final moisture contents can be tolerated. To reduce the spread to an acceptable level an extra step, named **equalizing**, is added to the drying schedule.

Equalizing can most efficiently be accomplished when the sample board or implanted electrode method for moisture content monitoring is being used (Chapter 7). Drying should be continued until the driest sample board is 2 to 3 percent moisture content below the target moisture content for the charge. The dry bulb temperature is then set at the highest level in the schedule and the wet bulb temperature is raised until the equilibrium moisture content in the kiln is equal to the desired final moisture content for the charge. At this setting boards which are above the target moisture content continue to dry, over-dried boards absorb moisture, and those at the target moisture content remain unchanged.

### To Remove Casehardening Stresses

Severe casehardening can be avoided by use of higher wet bulb temperatures early in drying and lower dry bulb temperatures later in drying. A degree of casehardening will be present after all drying schedules however, and if lumber is to be further manufactured the stresses should be removed. The basis for the treatment, named **conditioning**, is that wood becomes more plastic if its temperature and moisture content are raised. Upon becoming more plastic, or soft, it can yield to the stresses which are then neutralized.

In practice conditioning is carried out at the end of a schedule by raising the humidity, usually by steaming, for two to twelve hours depending on steam quality, wood thickness and the severity of the stresses as determined by the stress-prong test described earlier. Typically the drying conditions in the kiln are set to produce a 10°F wet bulb depression. High pressure steam is not satisfactory for conditioning since its very high temperature will actually cause a reduction of relative humidity. Conditioning following high temperature drying requires substantial cooling of a kiln and load first since it is usually not possible to raise wet bulb temperature above 180 to 185°F.

### Calculating Schedule Changes

Appendix A describes an arithmetical method that was developed to calculate changes in drying times for spruce, pine and alpine fir, provided some properties of the charges are known.

## Schedules For Western Species

The time-based schedules outlined below are a selection of many that have been shown to dry a given size (thickness up to 2 inches only) and grade of lumber to a required moisture content with a minimum of degrade. Not all combinations of species, size and product can be covered, but for operators requiring new schedules the examples provided can be tailored or modified to suit individual kilns or requirements. If changes are made with the prime intent of reducing drying time, the quality of drying must be closely monitored by extensive moisture content and grade checks after each new change.

Conditioning and equalizing steps should be added to schedules for upper grades of all species according to the guidelines provided earlier. The schedules have been arranged by species, and characteristics of each species relevant to drying are noted.

### Douglas-fir (*Pseudotsuga menziesii*)

Douglas-fir lumber is sawn in many sizes for finish lumber, structural lumber, decking, glulam stock, etc. There are, therefore, a great many schedules that can be used. The green moisture content of the species is low, average values being 30 to 40 percent for heartwood and 40 to 60 percent for mixed heartwood-sapwood.

**Douglas-Fir Clears and Upper Grades to 10-12% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 1 x 4 and 6 | 180 | 170 | 24 |
| | 190 | 150 | 36 |
| | | | 60 |
| 1 x 8 to 12 | 155 | 150 | 24 |
| | 165 | 150 | 24 |
| | 175 | 150 | 48 |
| | | | 96 |
| 5/4 and 6/4 x all widths | 165 | 160 | 8 |
| | 165 | 155 | 16 |
| | 170 | 155 | 24 |
| | 175 | 150 | 24 |
| | 185 | 150 | 48 |
| | | | 120 |
| 2 x 4 and 6 | 160 | 150 | 24 |
| | 165 | 145 | 24 |
| | 175 | 140 | 24 |
| | 180 | 140 | 24 |
| | 190 | 140 | 48 |
| | | | 144 |
| 2 x 8, 10 and 12 | 150 | 145 | 48 |
| | 160 | 145 | 24 |
| | 160 | 140 | 96 |
| | | | 168 |

The lumber dries relatively uniformly and few wet spot problems should be encountered. High-temperature drying from the start of a schedule is not recommended, except for 2 x 4 and 2 x 6 dimension lumber, due to the likely incidence of degrade. Knots in this species tend to loosen and break easily; therefore, care should be taken not to over-dry the lumber.

**Douglas-Fir Dimension and Lower Grades to 15-18% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 2 x 4 and 6 | 175 | 165 | 24 |
| | 180 | 165 | 24 |
| | 185 | 165 | 24 |
| | | | 72 |
| 2 x 4 and 6 (high temperature) | 180 | 160 | 18 |
| | 220 | 205 | 32 |
| | | | 50 |
| 2 x 8, 10 and 12 | 180 | 165 | 48 |
| | 180 | 155 | 24 |
| | | | 72 |

### Western Hemlock (*Tsuga heterophylla*) and Amabilis Fir (*Abies amabilis*)

These two species are grouped together as "hem-fir" in commercial practice and they are usually dried together. Lumber is sawn from them for the same general purposes as that from Douglas-fir.

**Hem-Fir Clears and Upper Grades to 10-12% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 1 x 4 and 6 | 155 | 150 | 24 |
| | 165 | 150 | 24 |
| | 175 | 150 | 24 |
| | 185 | 150 | 48 |
| | | | 120 |
| 1 x 8, 10 and 12 | 150 | 140 | 24 |
| | 160 | 150 | 24 |
| | 170 | 150 | 24 |
| | 175 | 150 | 24 |
| | 180 | 150 | 48 |
| | | | 144 |
| 2 x 4 and 6 | 160 | 150 | 24 |
| | 170 | 150 | 24 |
| | 180 | 150 | 48 |
| | 190 | 150 | 96 |
| | | | 192 |
| 2 x 8, 10 and 12 | 135 | 130 | 24 |
| | 140 | 130 | 24 |
| | 145 | 130 | 24 |
| | 150 | 130 | 24 |
| | 155 | 130 | 24 |
| | 160 | 130 | 24 |
| | 165 | 130 | 24 |
| | 165 | 125 | 24 |
| | 170 | 120 | 24 |
| | | | 216 |

The species group exhibits a very wide range of green moisture contents, ranging from about 55 percent in heartwood to about 165 percent in sapwood. Some heartwood of

hemlock is described as "sinker stock" and has green moisture contents up to about 200 percent and is very slow to dry. Lumber containing sinker heartwood usually contains wet pockets or streaks at the end of a normal drying schedule. Non-uniformity of final moisture contents within and between boards in kiln charges is probably the largest single problem in the kiln-drying of hemlock. Lengthening a schedule to try to dry the wet wood will cause the normal wood to over-dry with consequent increases in shrinkage-related defects. Compression wood occurs frequently in hemlock lumber and undergoes considerable longitudinal shrinkage upon drying. The resulting warp or cross-breaks in pieces containing compression wood are unavoidable and no schedule modifications should be undertaken because of them.

**Hem-Fir Dimension and Lower Grades to 15-18% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 2 x 4, 6 and 8 | 170 | 150 | 24 |
| | 180 | 150 | 48 |
| | 185 | 150 | 12 |
| | | | 84 |
| 2 x 4 and 6 (high temperature) | 225 | 205 | 24 |
| | 230 | 205 | 12 |
| | 235 | 205 | 12 |
| | 212 | 205 | 3 |
| | | | 51 |
| 2 x 10 and 12 | 155 | 140 | 12 |
| | 165 | 145 | 24 |
| | 180 | 150 | 24 |
| | 190 | 150 | 12 |
| | | | 72 |

## Western Red Cedar (*Thuja plicata*)

Red cedar is kiln-dried for finish, shop, paneling and siding lumber. Most schedules make use of conventional or low temperatures, but it is possible to dry it with combination schedules which begin with conventional temperatures and later change to high temperatures. Some red cedar is subject to collapse and it is characterized by having high heartwood moisture contents, up to 150 percent, compared with the normal average of 60 percent. Sapwood moisture contents can be as high as 250 percent. Collapse-prone lumber should be segregated and either air-dried for several weeks, to allow a slow drop in moisture content, or kiln-dried at low dry bulb temperatures of about 120°F until fiber saturation point is reached and the danger of collapse has passed.

## Yellow Cedar (*Chamaecyparis nootkatensis*)

Yellow cedar dries readily and the schedules given for western red cedar can be used. Green moisture contents average 32 percent for heartwood and 166 percent for sapwood.

**Cedar Clears and Upper Grades to 10-12% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 to 6/4 x all widths | 170 | 155 | 24 |
| | 180 | 150 | 24 |
| | 190 | 150 | 24 |
| | 190 | 140 | 48 |
| | | | 120 |
| 8/4 x all widths | 150 | 135 | 48 |
| | 160 | 135 | 24 |
| | 170 | 135 | 24 |
| | 170 | 125 | 144 |
| | | | 240 |

**Cedar Common Grades to 15-18% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 to 6/4 x all widths | 200 | 180 | 24 |
| | 200 | 170 | 24 |
| | 200 | 160 | 24 |
| | | | 72 |
| 2 x all widths | 160 | 150 | 24 |
| | 170 | 155 | 24 |
| | 175 | 155 | 24 |
| | 180 | 160 | 24 |
| | 190 | 165 | 24 |
| | | | 120 |

## White Spruce (*Picea glauca*)

White spruce is sawn and dried for both structural lumber and boards. Green moisture contents are high with heartwood averaging 62 percent and sapwood 148 percent. High temperature schedules are frequently used particularly for narrower widths and studs. The wood loses free water readily, therefore high air velocities can be used to promote fast-drying. Uniform final moisture contents can be expected with almost no wet pockets.

In production of dimension lumber, this species is commonly dried with lodgepole pine and alpine fir. Since the latter two dry slower, there is a danger of over-drying the spruce and increasing shrinkage-related defects.

## Sitka Spruce (*Picea sitchensis*)

Sitka spruce is very similar in properties to white spruce but since it grows to a larger size it can yield much higher quantities of clear lumber.

Schedules for clear grades of this species are the same as those used for clears of the white spruce.

**Spruce Upper Grades to 10-12% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 1 x 4, 6 and 8 (sapwood) | 160 | 145 | 12 |
| | 165 | 145 | 12 |
| | 170 | 145 | 12 |
| | 170 | 140 | 9 |
| | 170 | 135 | 6 |
| | | | 51 |
| 1 x 10 and 12 (sapwood) | 160 | 150 | 6 |
| | 165 | 150 | 6 |
| | 170 | 150 | 6 |
| | 175 | 150 | 6 |
| | 180 | 150 | 12 |
| | 180 | 145 | 6 |
| | | | 42 |
| 1 x 4 to 12 (heartwood) | 165 | 155 | 6 |
| | 170 | 150 | 6 |
| | 175 | 145 | 12 |
| | | | 24 |
| 6/4 x all widths | 160 | 150 | 24 |
| | 165 | 150 | 24 |
| | 170 | 150 | 24 |
| | 175 | 140 | 24 |
| | 180 | 130 | 24 |
| | | | 120 |
| 8/4 x all widths | 160 | 155 | 24 |
| | 170 | 155 | 24 |
| | 170 | 150 | 24 |
| | 175 | 150 | 24 |
| | 180 | 150 | 24 |
| | 180 | 140 | 24 |
| | | | 144 |

**Spruce (SPF) Lower Grades to 15-18% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 2 x 4 to 12 | 175 | 160 | 24 |
| | 180 | 160 | 24 |
| | 190 | 160 | 8 |
| | | | 56 |
| 2 x 4, 6 and 8 | 210 | 180 | 6 |
| | 210 | 170 | 12 |
| | 210 | 160 | 24 |
| | | | 42 |
| 2 x 4 | 230 | 170 | 28 |
| | | | 28 |

## Lodgepole Pine (*Pinus contorta*)

Lodgepole pine is usually sawn and dried for structural lumber. Green moisture contents average 38 percent for heartwood and 115 percent for sapwood.

It is frequently dried with western white spruce (see spruce schedule), but since the spruce dries faster, the final average moisture content of the spruce will be about 4 percent lower than that of the pine. Final moisture contents are more variable than with spruce, and wet pockets do occur. It can be high-temperature dried without causing undue degrade.

Lumber sawn from near the pith, particularly of small logs, has a tendency to twist. It is good idea to place substantial weights, e.g., steel rails or concrete blocks, on the top of kiln loads of such material to hold the uppermost rows straight during drying.

An increasing amount of lodgepole pine is now sorted to recover clear and upper grades which are dried with considerably milder schedules than for dimension lumber.

**Lodgepole Pine Upper Grades to 10-12% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 x all widths | 140 | 120 | 12 |
| | 145 | 120 | 12 |
| | 155 | 120 | 24 |
| | 165 | 130 | 24 |
| | | | 72 |
| 6/4 x all widths | 130 | 115 | 24 |
| | 140 | 115 | 24 |
| | 145 | 115 | 24 |
| | 160 | 125 | 24 |
| | | | 96 |
| 8/4 x all widths | 130 | 120 | 24 |
| | 140 | 120 | 24 |
| | 150 | 125 | 24 |
| | 150 | 120 | 60 |
| | | | 132 |
| 8/4 x all widths (elevated temperature) | 170 | 165 | 12 |
| | 170 | 160 | 12 |
| | 175 | 160 | 24 |
| | 180 | 160 | 24 |
| | 180 | 140 | 24 |
| | | | 96 |

## Western White Pine (*Pinus monticola*)

White pine is very similar in many properties to lodgepole pine. Green moisture contents average 62 percent for heartwood and 148 percent for sapwood.

The western pines are all subject to sap stain which may develop in logs when they are felled in warm, humid weather and left too long before sawing. These staining organisms are destroyed during the early stages of kiln-drying when the initial kiln temperatures are above 130°F.

Another stain common in the pines is known as "brown stain" or "kiln burn". This stain is not caused by living organisms but is thought to result from soluble extractives in the wood which are discolored by high kiln temperatures. As an alternative to using mild schedules in the kiln to prevent this stain a pre-treatment can be given to the green lumber to eliminate subsequent stain development. The treatment consists of dipping fresh sawn lumber in non-toxic, moderately alkaline salt solutions.

**White Pine Upper Grades to 10-12% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 x all widths | 130 | 115 | 24 |
| | 140 | 120 | 24 |
| | 160 | 135 | 36 |
| | | | 84 |
| 8/4 x all widths | 120 | 105 | 24 |
| | 130 | 115 | 24 |
| | 150 | 130 | 48 |
| | 155 | 130 | 48 |
| | | | 144 |

## Western Larch (*Larix occidentalis*)

Larch has drying characteristics similar to those of Douglas-fir. Where they occur together they are also dried together. Larch is the slower drier of the two, however, and for some purposes where tight control of moisture content variation is required, it is not practical to dry them together.

The average heartwood moisture content of larch is 35 percent and the sapwood value is 120 percent.

**Larch Upper Grades to 10-12% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 x all widths | 175 | 165 | 24 |
| | 175 | 160 | 24 |
| | 180 | 160 | 24 |
| | 180 | 150 | 24 |
| | | | 96 |

## Alpine Fir (*Abies lasiocarpa*)

Alpine fir is a difficult species to dry. Its green moisture contents average 56 percent for heartwood and 153 percent for sapwood. Final moisture contents are extremely variable with frequent occurrences of wet pockets.

This species is logged, milled, dried and sold with white spruce and lodgepole pine, the three species together comprising the dimension lumber spruce-pine-fir ("SPF") group. When all three are dried together, the spruce dries fastest, followed by pine as already noted, and the fir lags far behind. If drying continues so that the average moisture content of the total charge is 13 to 15 percent, then few if any of the alpine fir pieces may meet the 19 percent moisture content standard.

If the fir is segregated out, then it can be dried separately so that at least 95 percent of the charge will meet the 19 percent moisture content standard.

**Alpine Fir Lower Grades Dried to 15-18% MC**

| DB (°F) | WB (°F) | Time (h) |
|---|---|---|
| 150 | 140 | 12 |
| 160 | 140 | 12 |
| 175 | 150 | 12 |
| 200 | 150 | 24 |
| 230 | 150 | 24 |
| | | 84 |

## Red Alder (*Alnus rubra*)

Alder attains commercial size in the rich bottomlands of the coastal region. Although not widely utilized in British Columbia to date, it has considerable potential for processing into furniture components. Green moisture contents are extremely variable, ranging from 87 to 140 percent for mixed sapwood-heartwood. Although the wood dries readily it has a tendency to warp and consequently stickers should be placed not more than two feet apart.

**Alder Upper Grades to 8-10% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 x all widths | 170 | 160 | 12 |
| | 170 | 155 | 24 |
| | 170 | 145 | 24 |
| | 180 | 140 | 48 |
| | | | 108 |
| 8/4 x all widths | 140 | 130 | 48 |
| | 150 | 135 | 48 |
| | 160 | 135 | 48 |
| | 165 | 135 | 48 |
| | 170 | 140 | 48 |
| | 175 | 135 | 48 |
| | | | 288 |

## Broadleaf Maple (*Acer macrophyllum*)

This maple species has somewhat similar characteristics to red alder. Green moisture contents are lower however, ranging from about 59 to 106 percent to give an average of around 75 percent for mixed sapwood-heartwood. Maple has a strong tendency to end check; therefore it is good practice to ensure that the outermost stickers in a pile are at least flush with, or protrude beyond, the end of the boards. This will tend to slow end drying and help prevent excessive shrinkage and checking.

## Western White Birch (*Betula papyrifera*)

All seasoning characteristics of white birch are similar to those of broadleaf maple and it may be dried by the maple schedules.

**Maple and Birch Upper Grades to 8-10% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 x all widths | 140 | 130 | 48 |
| | 150 | 135 | 24 |
| | 160 | 140 | 24 |
| | 170 | 145 | 24 |
| | 170 | 135 | 24 |
| | | | 144 |

## Trembling Aspen (*Populus tremuloides*)

Trembling aspen is a relatively easy species to kiln-dry, either green from the saw or after air-drying. Sapwood and normal sound heartwood dry rapidly with few or no drying defects. Checking, which is a serious problem in kiln-drying of many

hardwood species, is not serious in aspen and the development of warp and drying stresses is no more serious than in many other woods.

One particular characteristic of the species is the presence of abnormal wood, occurring mainly in the zone between sapwood and heartwood. This wood is commonly referred to as "wetwood" simply because its most obvious property is that its moisture content is often very much greater than the surrounding normal wood. For example, typical moisture contents could be sapwood and heartwood 80 to 130 percent, and wetwood up to 200 percent. Wetwood dries slowly so that it is still wet when the normal wood is dry. Therefore, at the end of a drying run there are very large variations in moisture content within and between boards.

One other property of aspen and poplars in general, which is relevant to drying, is the presence of tension wood. While almost all shrinkage in normal wood is tangential and radial, tension wood does shrink significantly along the grain. Boards containing tension wood can twist, crook or bow during drying depending on the location of the tension wood in the piece. To minimize warp stickers should be placed only 18 to 24 inches apart.

**Aspen Upper Grades to 8-10% MC**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 4/4 to 6/4 x all widths | 160 | 140 | 72 |
| | 160 | 130 | 24 |
| | 170 | 130 | 24 |
| | 180 | 130 | 36 |
| | | | 156 |

**2 x 4 Studs to 15-18% MC**

| DB (°F) | WB (°F) | Time (h) |
|---|---|---|
| 70 to 240 (rises 2 1/2 °/hr) | to 160 | 68 |
| 240 | 160 | 28 |
| | | 96 |

## Other Special Drying Treatments

### Sterilizing

Normal kiln-drying at temperatures 140°F and above will kill all forms of fungi and insects including spores, eggs and larvae, thus sterilizing the lumber. Occasionally kilns may be used for the sole purpose of sterilizing; for example, of air-dried wood. To kill insects and larvae, a kiln temperature of 140°F for a minimum of 4 hours or 150°F for 2 hours should be used. For fungi, some importing countries require 6 hours at 160°F inside the wood. Added to this would be kiln heat-up time.

### Drying Part-Dried Lumber

All of the schedules listed earlier assume green or near-green lumber being dried. When drying part-dried stock the same dry and wet bulb settings can be used, but for upper grade stock it is recommended that at maximum wet bulb depression of 10°F be used for the first 12 hours of drying. It is particularly important that moisture contents be measured either manually or with an in-kiln moisture meter so that the schedule can be terminated before over-drying occurs.

### Drying Frozen Lumber

When drying frozen lumber a low-heat step (up to 140°F) should be used for about 4 to 6 hours to prevent degrade. Otherwise the temperature of the wood surface will rise rapidly in comparison to the core. The surface will therefore dry while the core is still frozen. This sets up a severe moisture gradient with a comparatively dry shell in which tensile stresses due to shrinkage will likely cause surface checking. The likelihood of this type of degrade increases with lumber thickness.

### Drying Heavy-Dimension Lumber

Time based schedules for softwoods greater that 2 inch (nominal) thickness have not been widely developed. A relatively mild schedule is provided below for 3 and 4 inch Douglas-fir, western hemlock, amabilis fir, lodgepole pine, alpine fir, and white spruce. This is a lengthy schedule that can be used as a starting base and gradually modified to suit operator requirements.

**Softwoods (Above) Upper Grades**

| | DB (°F) | WB (°F) | Time (h) |
|---|---|---|---|
| 12/4 and 16/4 x all widths | 130 | 125 | 12 |
| | 135 | 130 | 24 |
| | 140 | 135 | 48 |
| | 145 | 135 | 48 |
| | 150 | 135 | 48 |
| | 155 | 135 | 48 |
| | 160 | 135 | 48 |
| | 175 | 135 | 48 |
| | | | 324 |

Conditioning and equalizing steps to be added as required.

### Schedules For Dehumidifier Kilns

Low temperature dehumidifier kilns are designed to operate at temperatures that provide the most efficient rate of water extraction, and this largely depends on characteristics of the equipment supplied by different manufacturers. For this reason it is not always possible to provide general drying schedules which would give the optimum drying efficiency with all types, and it is recommended that guidance is obtained from the manufacturer.

Most low temperature (up to 160°F) kiln schedules can be used with the newer dehumidifiers that operate to this level of temperature. For schedules that exceed 160°F, a dehumidifier can partially compensate by using lower wet bulb temperatures although care must be taken to ensure that surface checks do not develop due to low kiln equilibrium moisture content.

The amount of water condensed from a dehumidifier can be measured and this provides a means of determining drying rates by applying the following expression:

$$MC_t = MC_i - \frac{100 \cdot M_w}{db \cdot V}$$

where: $MC_t$ = Moisture content at time t (%)
$MC_i$ = Initial moisture content (%)
$M_w$ = Mass of water removed to time t (kg, lb.)
db = Basic density ($kg/m^3$, $lb./ft.^3$)
V = Volume of wood ($m^3$, $ft.^3$)

Although this expression is simple to use, the accuracy of the result depends on the best estimate of initial moisture content and basic density.

# CHAPTER 11

# Quality Control

A dry kiln operator is responsible for one of the most important steps in the manufacture of lumber. The lumber must be dried to meet the appropriate standards or customer requirements, with as little degrade as possible and in as short a time as possible. Several elements of quality control and monitoring have been mentioned in earlier chapters. These and others that are summarized below should form the basis of an efficient lumber drying operation.

## Green Lumber Quality

The quality of seasoned lumber cannot be any better than that of the green lumber that was dried. In fact, defects in some pieces of green lumber may cause defects to develop in neighbouring pieces as well. Thick pieces take longer to dry and result in an unnecessarily high proportion of "wets". Alternately, if the charge is kept in the kiln until the thick lumber is dried most pieces will be overdried. This increases costs for two reasons: excessive kiln time is required and, because drying degrade increases at lower moisture contents, excessive degrade may result. A third problem arises when thick and thin pieces are piled together for drying. Because stickers do not restrain thin pieces placed between thick ones, the thin pieces may warp resulting in further degrade. It is therefore necessary that uniformly dimensioned lumber be produced for drying.

To determine whether defects are caused by drying or were already present, it is necessary to grade test packages before and after drying. Green grading should assign a grade and note any defects that might later be considered drying degrade. These would include shake, splits, loose knots and warp. After drying and planing the lumber is again graded. Losses due specifically to drying, for example increased warp or splits are noted, however manufacturing defects such as skip should not be considered as drying defects. Trim to remove drying degrade should be treated as a loss of volume. By applying market value before and after drying, the dollar loss (expressed as dollars per thousand board feet or as a percentage) can be calculated. This will indicate whether drying practices need to be changed, for example by use of a less severe drying schedule.

As described earlier, best drying results will be obtained when lumber of uniform properties is dried. In addition to ensuring that kiln loads comprise lumber of uniform thickness and width, consideration should be given to having green moisture contents as uniform as possible by presorting with a green moisture sensor.

## Dry Lumber Moisture Content

### Oven-Drying

The oven-drying method described earlier (Chapter 3) is the most direct and accurate process for measuring moisture content. It is however, very time consuming and requires destructive sampling of the wood. For quality control purposes, the main use of the oven-drying method is to calibrate portable or in-line moisture meters.

### Portable Moisture Meters

The calibration and use of portable or hand-held, resistance-type moisture meters was described earlier (Chapter 3). The inspection of lumber to determine the proportion not meeting the moisture content standards requires considerable care. Pieces must be selected for measurement without bias. This means that pieces known to be unusually dry along the sides and tops of a load must not be measured out of proportion to their occurrence in the charge. In practice, pieces should be selected as they move along the dry chain and only every fifth or tenth piece should be metered.

The number of readings required presents a problem. According to statistical theory, if 100 readings are taken and 5 are found to be over 19 percent moisture content, the actual proportion of the total load nonconforming may range from 3 to 7 percent. By taking 200 readings the range is narrowed to from 2.6 to 6.4 percent.

As each reading is taken, it should be tallied on a special sheet. Subsequently, the readings should be corrected for species and temperature, and the average moisture content of the charge determined. Two quantities, average moisture content and the percent over the maximum allowed, provide the quality control inspector with the information needed to assess the quality of lumber being produced.

The average moisture content and percent of nonconforming lumber will vary to some degree from day to day. A single day's sample may not give a representative record of the kiln's typical production. What is required is a continuing record so that sampling errors from day to day will cancel out and general trends and averages will be displayed. For this reason, each day's results should be plotted on a graph and only when

they are consistently or seriously nonconforming should the drying schedule be modified.

### Continuous Moisture Meters

Continuous or in-line moisture meters are moisture sensors designed to measure the moisture content of all lumber after kiln-drying either immediately before or immediately after the planer. The traditional use of these meters ahead of the planer has been to identify wet lumber, e.g., pieces exceeding 19 percent moisture content, which is then either marked with a dye spot so that it can be manually pulled off the line, or to activate an automatic drop-out to remove wet pieces from the infeed to the planer. They can be similarly used behind the planer although wet pieces will have been planed to dry finished size and will shrink further upon subsequent drying.

A second important quality control function of these meters is as a tool for measuring and recording kiln performance and uniformity. Present capabilities include compiling the moisture content of every board in turn and providing printed charts showing moisture distributions row by row and package by package on each kiln cart. In this way problem areas in a kiln can be identified if packages or carts from one area consistently show over-drying or under-drying. An example printout is shown in Figure 45.

The sensing heads for these meters come in various configurations including a single head below a feed chain with lumber passing lengthwise over it; up to four heads below a feed chain with lumber passing crosswise over them; and an over and under arrangement with lumber passing lengthwise between the heads.

Detailed description of the principles of operation of the meters is beyond the scope of this handbook other than to say that lumber passing through electrical fields generated by the sensors provides a signal or response that is interpreted as moisture content. Calibration is required for different species since wood density influences the readings obtained. This is best accomplished by passing individual wood samples through the meter sensing region(s), note readings obtained, and comparing with readings taken with a hand-held, resistance-type moisture meter.

## Kiln Operation

Good quality lumber, dried to specifications, is most efficiently produced when conditions required by the drying schedule are attained in practice. This requires that the recorder-controller instrument be calibrated and its operation checked at least every six months. Procedures for doing this are discussed in Chapter 8. Air velocity and temperature uniformity throughout the kiln should be checked yearly unless a consistent trend of over- or under-drying is apparent, in which case tests should be made immediately.

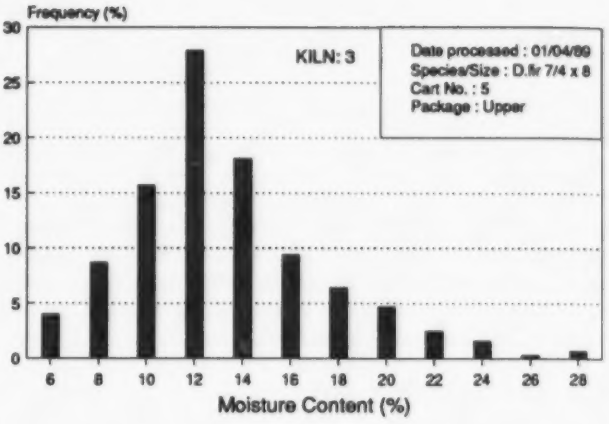


Fig 45 Printed record of moisture content distribution in one kiln package

## Kiln Records

The keeping of kiln records is an important phase of kiln operation. It is highly recommended that a complete drying record be maintained for each charge. Records serve several purposes:

1. They may be used to help refute claims that a certain charge of lumber was improperly or insufficiently dried.
2. They are a means by which an operator obtains experience and understanding of the drying characteristics of different woods. They provide the means to improve schedules when corrective measures are required, for example, to reduce degrade or drying times.
3. They indicate operating characteristics of a particular kiln and indicate whether or not it is functioning properly.
4. They provide management with a complete picture of the drying phase of the operation.

The following records should be kept and filed together:

### Recorder-Controller Chart

One of the most important records is the chart from a properly checked and calibrated recorder-controller which has the following functions:

1. It serves, during the drying period, as a ready reference as to what is going on in the kiln in terms of dry bulb and wet bulb temperatures at any given time; from these may be determined the relative humidity and equilibrium moisture content by use of a psychrometric chart or tables.
2. It may indicate malfunction in some part of the kiln or kiln equipment.

3. When drying is completed, the recorder-controller chart acts as a permanent record of conditions under which a particular charge was dried.

### Kiln Charge Record

The individual kiln charge record shows such particulars as kiln number, charge number, stock dried, quantity, dates in and out of kiln, final moisture content and total drying time. It may also provide space for explicit operating instructions as to schedule and other matters, and space for initialing as instructions are carried out.

Other spaces should be provided for final average moisture content, percentage "overs" and percentage degrade if this latter is determined. These figures may be referred to in case of moisture content claims in pinpointing trouble when properly dried lumber has been later subjected to adverse conditions, such as exposure to rain, or too long a period in a dry shed during weather of high relative humidity. In addition, the tally sheet for determining moisture content should be filed.

### Monthly Kiln Output

During the month as each charge is completed, all data are entered under headings that appear on the sheet: size, grade, species, average drying time, quantity (per charge and monthly total).

### Maintenance and Lost-Time Record

Separate sheets are maintained for individual kilns providing a complete record of maintenance performed by dates, and time lost by date and cause. They are vital to good drying practice.

# CHAPTER 12

# Storage and Transit of Dried Lumber

Improper handling and storage of kiln-dried lumber usually results in deterioration of lumber quality which is then attributed to poor drying practices.

Wood is a hygroscopic material and when exposed to specific conditions of temperature and relative humidity it will either gain or lose moisture until it reaches a moisture content in equilibrium with these conditions. Depending on location and local weather conditions at different times of the year, wood in sheltered outdoor conditions can equilibrate at 6 to 24 percent moisture content. In stickered packages all pieces will reach the same moisture content, and in close piles the outside pieces and the ends of all pieces will react similarly.

Dried lumber stored outside has the added risk of rain and snow. Moisture is absorbed readily and the surface moisture content quickly rises. Repeated wetting and drying of the surfaces gives lumber a very weathered appearance, and the swelling and shrinking that accompany the changes in moisture content cause surface checks. Rain falling on packaged lumber wets not only the outer surfaces but also is driven between the boards. While exposed surfaces dry readily, moisture can be retained within packages. The water can raise the moisture content to a level high enough to permit fungal growth leading first to stain and, if allowed to continue, to rot.

Dried lumber stored in a closed shed, or transported in a ship's hold with green lumber will rapidly gain in moisture content. This can occur due to direct contact between wet and dry packages or due to the increase in relative humidity of the air.

Problems can arise in winter in closed, heated buildings such as woodworking plants, when lumber that has been dried to a particular moisture content is then subjected to considerably lower equilibrium moisture content conditions. Outside cold air which can hold very little moisture enters the plant by forced or natural ventilation and is then heated to room temperature. Its relative humidity and equilibrium moisture content fall sharply and therefore, the wood dries further. Warping or checking can result and the wood can become difficult to process and unsatisfactory for use. Close control of relative humidity will prevent these problems.

Some of the above problems apply also to dried lumber that is in transit. Ideally, dry lumber should be transported in closed box cars or covered trucks to protect it from rain. This is not always possible and alternate methods must be used. Dry lumber transported on railway flatcars is often wrapped in plastic or waterproof paper. These covers are very effective provided that they are not damaged by poor handling or wind. The cost of wrapping is relatively high and there is the inconvenience of disposing of the used materials after delivery of the lumber.

Wrapped lumber may, in some circumstances, actually promote the build-up of moisture on lumber surfaces. Lumber that has been kiln-dried to a uniform moisture content of 15 percent contains between 3 and 4 pounds of water per cubic foot of wood. This water, in the form of bound water and water vapor, can move within the wood in response to changes in temperature. If the surface temperature of the wood falls, the vapor pressure at the surface falls, and moisture moves from the inside towards the surface and can evaporate from the surface.

If moisture evaporating from the surface is contained within the wrapping material, in time it may condense and collect as a liquid. The wood surface can then be wetted sufficiently to support fungal growth. The problem can become particularly serious if the package contains lumber that has pockets of moisture considerably higher than 15 percent. Wet pocket species, such as western hemlock and alpine fir, can be involved in this problem.

To reduce the problem of moisture build-up inside wrappers, a breather-type of paper wrap should be used rather than plastic which is a very efficient vapor barrier. Breather-type paper will resist entry of rain and snow but it will allow movement of water vapor out of the package.

An alternative to wrapping is treatment with a water-repellant chemical. A number of products are available which can be applied by dipping or spraying.

# APPENDIX A

## Calculating Kiln Schedule Changes

*(Modified from Bramhall, G., Calculating Kiln Schedule Changes, Canadian Forest Industries, September, 1975.)*

The modification of schedules to meet new conditions is traditionally a trial-and-error process. Because it is difficult in most kilns to monitor average moisture content during drying, there is a high probability that when the charge is removed the final moisture content will be either too high, in which case the lumber will not conform to standards, or too low, in which case drying times will be unnecessarily long and there will be an increased possibility of degrade.

This article describes how to modify kiln schedules provided that drying is limited to "conventional" or "low-high" schedules including step-wise and continuously changing schedules. High-temperature drying involves different principles and the procedures described here do not apply.

The concept involved is that a specific amount of "drying effort" is required to dry from a given initial to a given final moisture content and, provided the drying characteristics of the species are known, that value can be calculated. Any setting of dry bulb temperature and wet bulb temperature provides a specific amount of drying effort every hour and this also can be calculated. When the total drying effort produced by the schedule equals that required by the lumber, the lumber will have reached the desired final moisture content. Since the drying rate is also affected by factors not involved in these calculations the time estimates for any chosen schedule are approximate only. Differences between kiln operations, e.g., air velocity, sticker thickness, lumber thickness and schedule type, will result in consistent differences between predictions made and results actually obtained. These can be corrected for, and subsequent predictions made more reliable, by calculating a "kiln factor" and applying this to subsequent calculations.

At this time, tables have been calculated for only 2 inch lumber of western white spruce, lodgepole pine and alpine fir. To use the system it is necessary to know the initial moisture content of the lumber and the final desired moisture content. Where the initial moisture content is not known an average value characteristic of the species may be used without a great deal of error. For spruce, lodgepole pine and alpine fir these values are 50, 60 and 80 percent, respectively.

The amount of drying effort required to dry from a given initial to a given final moisture content is determined from the appropriate species table (Tables 2 to 4) by subtracting the drying effort of the initial moisture content from that of the final moisture content.

The amount of drying effort produced per hour for given settings of dry bulb temperature and wet bulb temperature are found from Table 1 by subtracting the vapor pressure of the wet bulb temperature from that of the dry bulb temperature. Where a setting is held for several hours, the drying effort of that setting is found by multiplying by the number of hours. The drying effort for the entire schedule is found by adding the effort of the various settings. Because equalization and conditioning periods do not dry the lumber significantly, these should not be included in the calculations.

The kiln factor for any kiln is found by dividing the drying effort of a schedule used in that kiln (Table 1) by the effort determined from the difference of initial and final moisture content of the charge dried by that schedule (Tables 2 to 4). This is later used to multiply the values of Tables 2 to 4 to get the proper value for that kiln.

A series of examples is provided.

1. Assume you are using the following schedule, and are able to dry lodgepole pine from 45 percent to 12.7 percent moisture content in 54 hours:

   | | |
   |---|---|
   | 180-160 | 10 hours |
   | 190-160 | 20 hours |
   | 200-165 | 24 hours |

   What is the drying effort of your schedule?

   Using Table 1 to obtain drying effort produced per hour, subtract the vapor pressure of the wet bulb temperature from that of the dry bulb temperature and multiply by the number of hours the settings are held.

| Settings | Drying Effort | x Time |
|---|---|---|
| 180 - 160 | 518 - 327 = 191 x 10 = | 1910 units |
| 190 - 160 | 644 - 327 = 317 x 20 = | 6340 units |
| 200 - 165 | 795 - 368 = 427 x 24 = | 10248 units |

   Total drying effort produced by schedule is 18498 units.

2. What drying effort is required, according to Table 3, to dry lodgepole pine from 45 percent to 12.7 percent moisture content?

   | | | |
   |---|---|---|
   | Drying effort at 12.7% | = 24340 | units |
   | Drying effort at 45% | = 2916 | units |
   | Drying effort required to dry lumber | = 21424 | units. |

3. What is the kiln factor for your kiln?

   Kiln factor = 18498/21424 = 0.86

4. You wish to dry your lumber in 48 hours to 13.0 percent moisture content. How can this be done?

   (a) First find the drying effort required in your kiln, using Table 3 and the kiln factor:

   Drying effort at 13% = 23482 units
   Drying effort at 45% = 2916 units
   Difference = 20566 units

   Multiply by the kiln factor 0.86 = 17687 units, which is the drying effort required for your kiln.

   (b) Now, find a combination of dry bulb temperature, wet bulb temperature and time which will produce approximately 17687 units in 48 hours. Since the method described here gives no indication of how the schedule will affect lumber quality, an operator must use his experience to avoid excessively severe conditions. By starting with the same temperatures as before, and increasing the wet bulb depression somewhat more rapidly, a satisfactory final moisture content in the desired time should be obtained with no significant degrade.

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 180 | - | 160 | 8 hours | 518 | - | 327 | = | 191 | x 8 | = 1528 |
| 190 | - | 160 | 8 hours | 644 | - | 327 | = | 317 | x 8 | = 2536 |
| | | | | | | Total at 16 hours | | | | = 4064 |

After 16 hours drying, 17687-4064 = 13623 units are still required. If these are produced in the remaining 32 hours, this will require 13623/32 = 426 units per hour. If we maintain 160 wet bulb temperature, the dry bulb temperature will require a vapor pressure of 327+426 = 753, which is between 197 and 198°F (Table 1). So a final setting of 198 - 160 for 32 hours will complete the schedule satisfactorily. Many other combinations could be found with the same end result.

5. The system can be used with continuously changing schedules, but the drying time must be handled a few hours at a time, averaging the temperature over that period. Five or six hour periods are recommended. With the schedule being used or considered, determine dry and wet bulb temperatures every 6 hours, take the average for each 6 hour period, and apply these values for the entire 6 hour period. An example is worked out as follows: (see also Figure A-1).

   If the wet bulb is fixed at 160°F and the dry bulb increases from 180°F at 1°F per hour, how many hours will be required to provide 17687 units to dry lodgepole pine from 45 percent to 13 percent in the kiln considered in the earlier example?

   Since we are now close to the required value of 17687 units, we can calculate how much more drying is required, and how long this would take at the final setting.

| | | |
|---|---|---|
| Required amount | = | 17687 - 16206 = 1481 units. |
| Final setting | = | 216 - 160°F or |
| | | 1097 - 327 units = 770 units per hour. |
| Time required | = | 1481/770 = 1.9 hours. |
| Total time required | = | 36 + 1.9 = 37.9 hours. |

**Table 1.** Vapor Pressure of Water at Temperatures From 100 to 239°F (mb)

| Temp.°F | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 66 | 68 | 70 | 72 | 74 | 76 | 78 | 81 | 83 | 85 |
| 110 | 88 | 91 | 93 | 96 | 99 | 102 | 104 | 107 | 110 | 114 |
| 120 | 117 | 120 | 123 | 127 | 130 | 134 | 138 | 141 | 145 | 149 |
| 130 | 153 | 158 | 162 | 166 | 171 | 175 | 180 | 184 | 189 | 194 |
| 140 | 199 | 204 | 210 | 215 | 221 | 226 | 232 | 238 | 244 | 250 |
| 150 | 257 | 263 | 269 | 276 | 283 | 290 | 297 | 304 | 312 | 319 |
| 160 | 327 | 335 | 343 | 351 | 360 | 368 | 377 | 386 | 395 | 404 |
| 170 | 413 | 423 | 433 | 443 | 453 | 463 | 474 | 485 | 496 | 507 |
| 180 | 518 | 530 | 541 | 554 | 566 | 578 | 591 | 604 | 617 | 630 |
| 190 | 644 | 658 | 672 | 687 | 701 | 716 | 731 | 747 | 763 | 779 |
| 200 | 795 | 812 | 828 | 846 | 863 | 881 | 899 | 917 | 936 | 955 |
| 210 | 974 | 994 | 1014 | 1034 | 1054 | 1075 | 1097 | 1118 | 1140 | 1163 |
| 220 | 1185 | 1208 | 1232 | 1256 | 1280 | 1304 | 1329 | 1355 | 1380 | 1407 |
| 230 | 1433 | 1460 | 1487 | 1515 | 1543 | 1572 | 1601 | 1631 | 1661 | 1691 |

**Table 2.** Drying Effort Required For 2 Inch Western Spruce (mb-hr)

| mc | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 18599. | 18435. | 18271. | 18109. | 17949. | 17790. | 17632. | 17476. | 17321. | 17168. |
| 11 | 17016. | 16865. | 16715. | 16567. | 16420. | 16275. | 16131. | 15988. | 15846. | 15706. |
| 12 | 15567. | 15429. | 15292. | 15157. | 15022. | 14889. | 14757. | 14626. | 14497. | 14268. |
| 13 | 14241. | 14115. | 13990. | 13866. | 13743. | 13621. | 13501. | 13381. | 13262. | 13145. |
| 14 | 13028. | 12913. | 12799. | 12685. | 12573. | 12461. | 12351. | 12241. | 12133. | 12026. |
| 15 | 11919. | 11813. | 11709. | 11605. | 11502. | 11400. | 11299. | 11199. | 11100. | 11001. |
| 16 | 10904. | 10807. | 10712. | 10617. | 10523. | 10429. | 10337. | 10245. | 10155. | 10065. |
| 17 | 9975. | 9887. | 9800. | 9713. | 9627. | 9541. | 9457. | 9373. | 9290. | 9208. |
| 18 | 9126. | 9045. | 8965. | 8886. | 8807. | 8729. | 8651. | 8575. | 8499. | 8424. |
| 19 | 8349. | 8275. | 8202. | 8129. | 8057. | 7986. | 7915. | 7845. | 7775. | 7706. |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 7638. | 6988. | 6393. | 5848. | 5350. | 4895. | 4478. | 4096. | 3748. | 3429. |
| 30 | 3137. | 2869. | 2625. | 2402. | 2197. | 2010. | 1839. | 1682. | 1539. | 1408. |
| 40 | 1288. | 1178. | 1078. | 986. | 902. | 825. | 755. | 691. | 632. | 578. |
| 50 | 529. | 484. | 443. | 405. | 371. | 339. | 310. | 284. | 260. | 237. |
| 60 | 217. | 199. | 182. | 166. | 152. | 139. | 127. | 116. | 107. | 98. |
| 70 | 89. | 82. | 75. | 68. | 62. | 57. | 52. | 48. | 44. | 40. |

**Table 3.** Drying Effort Required For 2 Inch Lodgepole Pine (mb-hr)

| mc | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 35060. | 34534. | 34021. | 33520. | 33031. | 32554. | 32088. | 31633. | 31188. | 30753. |
| 11 | 30328. | 29912. | 29505. | 29108. | 28719. | 28338. | 27966. | 27601. | 27244. | 26894. |
| 12 | 26552. | 26216. | 25888. | 25566. | 25250. | 24941. | 24637. | 24340. | 24048. | 23762. |
| 13 | 23482. | 23206. | 22936. | 22671. | 22411. | 22155. | 21904. | 21658. | 21416. | 21178. |
| 14 | 20945. | 20716. | 20490. | 20269. | 20051. | 19837. | 19627. | 19420. | 19217. | 19017. |
| 15 | 18820. | 18627. | 18437. | 18249. | 18065. | 17884. | 17706. | 17530. | 17357. | 17187. |
| 16 | 17019. | 16854. | 16692. | 16532. | 16375. | 16219. | 16066. | 15916. | 15767. | 15621. |
| 17 | 15477. | 15335. | 15195. | 15057. | 14921. | 14787. | 14655. | 14524. | 14396. | 14296. |
| 18 | 14144. | 14021. | 13899. | 13779. | 13661. | 13544. | 13428. | 13315. | 13203. | 13092. |
| 19 | 12982. | 12874. | 12768. | 12663. | 12559. | 12456. | 12355. | 12255. | 12157. | 12059. |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 20 | 11963. | 11062. | 10262. | 9547. | 8904. | 8325. | 7801. | 7324. | 6889. | 6491. |
| 30 | 6125. | 5788. | 5478. | 5190. | 4923. | 4675. | 4444. | 4228. | 4026. | 3837. |
| 40 | 3660. | 3493. | 3336. | 3188. | 3048. | 2916. | 2791. | 2673. | 2560. | 2454. |
| 50 | 2352. | 2256. | 2164. | 2076. | 1992. | 1912. | 1836. | 1763. | 1693. | 1626. |
| 60 | 1561. | 1500. | 1440. | 1383. | 1329. | 1276. | 1225. | 1176. | 1129. | 1084. |
| 70 | 1040. | 988. | 957. | 918. | 879. | 843. | 807. | 772. | 739. | 707. |

**Table 4.** Drying Effort Required For 2 Inch Alpine Fir (mb-hr)

| mc | 0. | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 40021. | 39801. | 39583. | 39366. | 39150. | 38935. | 38722. | 38509. | 38298. | 38088. |
| 11 | 37879. | 37671. | 37465. | 37259. | 37055. | 36852. | 36649. | 36448. | 36248. | 36050. |
| 12 | 35852. | 35655. | 35460. | 35265. | 35072. | 34879. | 34688. | 34498. | 34309. | 34120. |
| 13 | 33933. | 33747. | 33562. | 33378. | 33195. | 33013. | 32832. | 32652. | 32473. | 32294. |
| 14 | 32110. | 31941. | 31766. | 31592. | 31418. | 31246. | 31075. | 30904. | 30735. | 30566. |
| 15 | 30399. | 30232. | 30066. | 29901. | 29737. | 29574. | 29412. | 29251. | 29090. | 28931. |
| 16 | 28772. | 28614. | 28457. | 28301. | 28146. | 27991. | 27838. | 27685. | 27533. | 27382. |
| 17 | 27232. | 27083. | 26934. | 26786. | 26640. | 26493. | 26348. | 26204. | 26060. | 25917. |
| 18 | 25775. | 25633. | 25493. | 25352. | 25214. | 25076. | 24938. | 24801. | 24665. | 24530. |
| 19 | 24395. | 24262. | 24129. | 23996. | 23865. | 23734. | 23604. | 23474. | 23345. | 23217. |
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 20 | 23090. | 21854. | 20685. | 19578. | 18530. | 17538. | 16600. | 15712. | 14871. | 14075. |
| 30 | 13322. | 12609. | 11934. | 11295. | 10691. | 10119. | 9577. | 9065. | 8580. | 8121. |
| 40 | 7686. | 7275. | 6885. | 6517. | 6168. | 5838. | 5526. | 5230. | 4950. | 4685. |
| 50 | 4434. | 4197. | 3973. | 3760. | 3559. | 3368. | 3188. | 3017. | 2856. | 2703. |
| 60 | 2558. | 2422. | 2292. | 2169. | 2053. | 1943. | 1839. | 1741. | 1648. | 1560. |
| 70 | 1476. | 1397. | 1322. | 1252. | 1185. | 1121. | 1061. | 1004. | 951. | 900. |

**Figure A-1.**

| Hours | Settings | Average | Drying Effort | Cumulative Total |
|---|---|---|---|---|
| 0 | 180 - 160 | --- | 0 | |
| 6 | 186 - 160 | 183 - 160 | (554 - 327) x 6 = 1362 | 1362 |
| 12 | 192 - 160 | 189 - 160 | (630 - 327) x 6 = 1818 | 3180 |
| 18 | 198 - 160 | 195 - 160 | (716 - 327) x 6 = 2334 | 5514 |
| 24 | 204 - 160 | 201 - 160 | (812 - 327) x 6 = 2910 | 8424 |
| 30 | 210 - 160 | 207 - 160 | (917 - 327) x 6 = 3540 | 11964 |
| 36 | 216 - 160 | 213 - 160 | (1034 - 327) x 6 = 4242 | 16206 |

# APPENDIX B

## Definitions

***Air velocity*** The speed at which air moves through a load of lumber in a kiln, generally measured in feet per minute on the leaving-air side of a load.

***Baffle*** A piece of material used to deflect, check or otherwise direct the flow of air through the loads of lumber in a kiln. Improper loading and/or baffling leads to short-circuiting of the air movement.

***Blanking*** Presurfacing of green lumber, usually on one side only, prior to kiln-drying in order to obtain uniform thickness of lumber.

***Bolster (or bunk)*** A square timber placed between stickered packages of lumber to provide for entry and exit of the forks of a lift truck.

***British thermal unit ("Btu")*** The amount of heat necessary to raise 1 pound of water 1°F in temperature.

***Bulb, control*** The temperature-sensitive part of a thermostatic control system.

- *Dual control* Two bulbs of a Y-shaped control system. They are usually located on each kiln wall directly opposite each other and control the temperature of the entering air regardless of the direction of air movement.
- *Recorder* A temperature-sensitive instrument that records but does not control kiln temperatures.
- *Recorder-controller* An instrument that records the dry and wet bulb temperatures within the drying chamber and automatically controls them according to some predetermined schedule.

***Bulk-pile*** A solid-piled package of lumber.

***Cam*** One of two precut metal discs, one representing the pattern of dry bulb temperatures with time, the other wet bulb temperatures with time; used in a control instrument to provide the schedule to be automatically followed.

***Casehardening*** A condition of set in wood under stress. The outer fibers (face) are under compressive stress and the inner fibers (core) are under tensile stress.

***Casehardening, reverse*** A final stress and set condition in wood where the outer fibers (face) are under tensile stress and the inner fibers (core) are under compressive stress; the result of over-correction for casehardening.

***Chamber, plenum*** Conduit or space on the pressure side of a fan or blower in which the air is maintained under a small positive pressure.

***Chart, recorder*** A paper sheet, usually circular, on which a graphic record of kiln temperatures is transcribed.

***Coil, heating***

- *Syn* Pipe coil. In kiln-drying a heat exchanger made of two or more runs of plain or finned pipes in the dryer through which steam, hot water, or hot oil flows to heat the circulated air.
- *Booster or reheater* A supplementary coil, usually located between tracks of a double-track kiln, used to add heat to air that has already cooled by moving through a truckload.

***Collapse*** The severe distortion of single cells which may occur in wood during the early stages of drying. Evidenced by caved-in appearance of the surface of the lumber.

***Compression wood*** Abnormal wood formed on the lower side of trunks of leaning softwood trees. It shrinks longitudinally more than normal wood, causing bow, crook and twist.

***Condensation*** The changing of a vapor to liquid form. Steam releases 970 Btu per pound in changing to liquid water.

***Conditioning*** Any process designed to produce a uniform distribution (equalization) or moisture in timber and reduce drying stresses.

***Controller*** An instrument that automatically controls kiln temperatures.

***Course*** Single layer of lumber of the same thickness in a stickered pile or package.

***Degrade, drying*** A drop in lumber grade due to defects that result from seasoning.

***Depression, wet bulb*** The difference between dry bulb and wet bulb temperatures.

***Diffusion*** Spontaneous movement of heat, dissolved material, moisture or gas through a body or space from high points to low points of temperature, concentration or partial pressure.

***Drying rate*** The amount of moisture lost from lumber per hour of drying time, usually expressed as percentage decrease in moisture content per hour.

***Duct, air*** A rectangular, square, or circular passageway to conduct air.

***End coating*** Moisture-resistant coating applied to end-grain surfaces of green lumber to restrict checking and splitting resulting from rapid end drying.

***Equilibrium moisture content ("emc")*** The moisture content at which wood neither gains nor loses moisture when subjected to a given constant condition of humidity and temperature. The moisture content which wood attains when subjected to any given constant condition of humidity and temperature.

***Evaporation*** Conversion of a liquid to the vapor state by the addition of latent heat (970 Btu per pound of water at 212°F).

***Extractives*** Substances on wood, not an integral part of the cellular structure, that can be removed by hot or cold water, ether, benzene, or other solvents that do not react chemically with wood substance.

***Fiber saturation point ("fsp")*** The stage in the drying of wood at which the cell walls are saturated with water, but the cell cavities are free from water. It is taken at normal temperatures as approximately 30 percent moisture content. At higher temperatures, its value decreases. At the boiling point of water it is approximately 19 percent.

***Honeycombing*** Checks, which occur in the interior of a piece of wood, usually along the wood rays, and may not be visible at the surface.

***Humidity, absolute*** The weight of water vapor per unit volume of space.

***Humidity, relative*** Ratio of the amount of water vapor present in the air to that which the air would hold at saturation at the same temperature.

***Hygrometer*** An instrument, usually consisting of two thermometers, for measuring the dry bulb and wet bulb temperatures of the air.

***Hygroscopicity*** The property of a substance which permits it to absorb and retain moisture.

***Juvenile wood*** Low density, fast-growing wood formed near the pith of a tree; also known as core wood.

***Kiln*** A chamber provided with controls for temperature and relative humidity in which lumber is dried.

- *Compartment* A dry kiln in which the total charge of lumber is dried as a single unit.
- *Progressive* A dry kiln in which the total charge of lumber is dried as several units, such as kiln truckloads, that move progressively through the kiln. The temperature is lower and the relative humidity higher at the entering (green) end than at the discharge (dry) end.
- *Multiple track* A dry kiln equipped with two or more tracks.
- *Reversible circulation* A dry kiln in which the direction of air circulation can be reversed at desired intervals.
- *Single track* A dry kiln equipped with one track.

***Kiln charge*** The total amount of lumber or wood items in a dry kiln.

***Kiln-drying*** Process of drying lumber under controlled conditions in a dry kiln.

***Kiln run*** Term applied to the drying of a single charge of lumber.

***Meter, moisture*** An instrument for automatically determining the moisture content of wood, equipped with electrically conducting electrodes which may be driven into the wood or which are flat and contact the wood surface. Readings must be adjusted to compensate for species and temperature of the wood.

***Moisture, bound*** Water in wood that is found in the cell walls and held by hygroscopic forces: preferably called "bound water".

***Moisture, free*** Moisture in the cell cavities and inter-cellular spaces of wood, as distinguished from moisture in cell walls; preferably called "free water".

***Moisture content ("mc")*** The weight of water held in wood, usually expressed as a percentage of the oven-dry weight; the percentage of moisture present in wood. The moisture may exist (a) free in cell spaces or (b) in the cell walls.

- *Air-dry moisture content* The moisture content of wood that is in equilibrium with climatic conditions.
- *Green moisture content* The moisture content of unseasoned wood that may vary from 30 to 200 percent.
- *Kiln-dry moisture content* The moisture content of wood that has been dried in a kiln. According to present standards for construction lumber, each piece must be less than 19 percent moisture content.
- *Oven-dry* Wood that has been dried to constant weight in an oven at 217 ± 4°F (103 ± 2°C).

***Moisture distribution*** The varying concentration of moisture throughout a piece of wood, usually from face to face but sometimes from end to end.

***Moisture gradient*** A condition of graduated moisture content between the inner and outer portions of wood due to loss or absorption of moisture.

***Piling, box*** A method of flat piling random-length lumber whereby both ends of a pile are square.

***Piling, close*** Lumber piled edge to edge with no space between courses; solid or bulk piling; the normal way in which lumber is shipped.

***Piling, flat*** Lumber piled so that the broad faces of boards are horizontal.

***Reaction wood*** Wood of more or less distinctive anatomical characteristics formed in parts of leaning or crooked stems; in hardwoods termed tension wood and in softwoods, compression wood.

***Sample board*** A board from which one or more kiln samples will be cut and placed in a kiln charge, so that they can be removed for examination, weighing and testing; or a board within a kiln truckload sampled for moisture content during or after a run.

***Set*** A localized, semipermanent deformation in wood caused by internal stresses.

- *Compression set* Set, occurring during compression, that tends to give wood a smaller than normal dimension after drying, usually found in the interior of wood items during the last stage of drying, but sometimes in the outer layers after over-conditioning or rewetting.
- *Tension set* Set, occurring during tension that tends to give wood a larger than normal dimension, usually occurring in the outer layers during the first stages.

***Shrinkage*** Contraction caused by drying wood below the fiber saturation point; greater in the wide face of flat-grain than in edge-grain lumber, and minimal in the longitudinal direction.

***Sorting*** Segregation of lumber into lots having similar characteristics, such as thickness, species, grade, initial moisture content, final moisture content, and into stacking classes by thickness, width and length.

***Specific gravity*** The ratio of the oven-dry weight of a piece of wood to an equal volume of water at 39°F (4°C). It is normally based on the green volume of the wood.

***Spray line*** A plain pipe of varying sizes and lengths, drilled with holes of various sizes and spacing, through which steam or water droplets are injected into a kiln.

***Stain, blue*** A bluish or grayish discoloration in the sapwood of softwoods caused by the growth of certain dark-colored (staining) fungi.

***Stain, brown*** A brownish discoloration that may occur during the seasoning of certain softwoods (particularly white pine), apparently caused by the concentration and oxidation of extractive chemicals.

***Steam*** The vapor into which water is converted when heated above the boiling point.

- *Exhaust* Steam which has been passed through a steam engine or machine; usually of low pressure.
- *Live* Steam obtained directly from a boiler.
- *Saturated* Steam in contact with liquid water at the same temperature and pressure.
- *Superheated* Steam at a temperature higher than the saturation temperature corresponding to the pressure.

***Sticker*** A wood strip or crosser placed between courses of lumber in a pile or a unit package, at right angles to the long axis of the stock. It permits air passage between adjacent courses.

***Stress, drying*** An internal force, caused by uneven drying and shrinking, and influenced by set.

- *Tensile stress* The stress found in the outer layers of wood during the early stages of drying, when shrinkage is restrained by the still-wet interior regions; also the stress in the interior layers in drying as they try to shrink, but are restrained by the set, outer shell.
- *Compressive stress* The stress found in the interior region of wood during the early stages of drying, caused by shrinking of the outer shell; also the stress in the outer layer later in drying caused by the shrinking of the interior.

***Stress-free*** Containing no drying stresses.

***Stress-relief*** See Conditioning.

***Stress-section*** A cross-section of a sample that is cut into prongs of equal thickness from face to face, in order to determine the presence of stresses in the wood.

***Temperature, dry bulb*** The air temperature indicated by any type of thermometer not affected by the relative humidity of the air.

***Temperature, wet bulb*** The temperature of a thermometer set in a wind current, the sensitive element of which is covered by a smooth, clean, soft , water-saturated cloth.

***Tension wood*** Abnormal wood formed on the upper side of the trunk of leaning hardwood trees. It shrinks more than normal wood longitudinally; is subject to wet spots in drying and fuzzy surface on machining.

***Treatment, antistain*** A chemical applied to lumber by dipping or spraying to prevent or retard development of chemical or fungus stain (mould or sapstain). It is recommended for green and close-piled underdried lumber.

***Treatment, steaming*** Spraying steam directly into a kiln to attain a condition at or near saturation in the initial stages of kiln drying to retard the growth of mould. It is also used to increase the rate of heating of cold lumber, but it is not the same process as conditioning.

***Vapor pressure*** Pressure exerted by a confined body of vapor; at saturation, the pressure is a function of temperature only.

***Vent*** An opening in a kiln roof or wall that can be opened or closed in order to permit escape of humidity, to assist in maintaining the desired relative humidity condition within the kiln. Most vents have automatic control.

- *Linkage* The adjustable, pivoted rods connecting the vent cover to an air piston which facilitates the opening and closing of the vents.

***Waterpocket*** A zone within green or dried lumber having excessively high moisture content; common to alpine fir, hemlock, aspen.

***Water repellent*** A compound designed to give temporary waterproofing to wood products in transit and storage; usually a wax emulsion applied by spraying.

***Wet wood*** Pockets within wood having one or more of the following characteristics: high moisture content; presence of bacterial (but not decay fungi); usually but not always with lower acidity than adjacent wood; lower permeability than normal wood. Common in poplar wood.

***Moisture content, air velocity and temperature designations*** The following approximate moisture content values are important:

| | |
|---|---|
| Lower limit of fungal growth | 22% |
| Air-dried lumber | 12 to 16% |
| Exterior woodwork | 16% |
| Interior joinery with central heating | 6 to 8% |

Temperature ranges for drying classifications:

(a) Low temperature, less than 140°F (60°C).
(b) Conventional, 140-180°F (60-80°C).
(c) Elevated, 180-212°F (80-100°C).
(d) High temperature, more than 212°F (100°C).

Classification of air delivery on the basis of exit air in feet per minute ("fpm") or meters per minute ("m per min."):

(a) Standard, up to 300 fpm (90 m per min.).
(b) Accelerated, 300-500 fpm (90-150 m per min.).
(c) High velocity, more than 500 fpm (over 150 m per min.).